6. Proposed models for the assessment of the rex sole stock in the Gulf of Alaska

By

Carey R. McGilliard

Resource Ecology and Fisheries Management Division
Alaska Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
7600 Sand Point Way NE., Seattle, WA 98115-6349

Executive Summary

A full, age-structured assessment will be presented in November 2025 for GOA rex sole. Here we present small, but necessary updates to improve the quality of the model. The GOA rex sole assessment is a Tier 3a two-area model with growth estimated separately in each area.

Summary of Changes in Assessment Inputs

The following data sources were updated with newest years of data:

(1) 2022-2024 catch biomass was added to the model
(2) 2021 catch biomass was updated to reflect final (rather than projected) 2021 catches
(3) 2022-2024 fishery length composition data were added to the model and 2021 fishery length composition data were updated to reflect October – December 2021 catches
(4) 2021-2022 fishery age composition data were added to the model
(5) 2023 GOA trawl survey biomass estimate was added to the model
(6) 2023 GOA trawl survey length composition data were added to the model
(7) Note: no new GOA trawl survey age-at-length data were added to the model (not aged yet at time of analysis)

Summary of Changes in Assessment Methodology

(1) Fishery age composition data were processed using "sampler" code (see CIE discussion paper)
(2) Survey biomass logspace standard errors were corrected (the 2021 assessment mistakenly used CV instead of logspace standard error, which were slightly different; see CIE discussion paper)
(3) Age double reads were analyzed and an ageing error matrix accounting for ageing uncertainty was added to the model
(4) An alternative model was run fixing historical catchability and natural mortality prior to 2022 and estimating catchability and natural mortality from 2022 onwards to account for a low survey biomass estimate in 2023. This approach has limitations and we discuss using alternative models to inform management quantities via the risk table framework instead.

Responses to SSC and Plan Team Comments on Assessments in General

GOA PT, November 2021: The Team recommends all GOA authors evaluate any bottom trawl survey information used in their assessment prior to 1990 including the 1984 and 1987 surveys and conduct sensitivity analyses to evaluate their usefulness to the assessment. This may apply for Aleutian Islands surveys but this was only raised during GOA assessment considerations.

The 2021 assessment excluded most 1984 and 1987 survey data, but mistakenly included survey biomass estimates for the Eastern GOA. We removed the 1984 and 1987 data points (see CIE review discussion paper) and they are excluded in the new base case run presented here.

Responses to SSC and Plan Team Comments Specific to this Assessment

GOA PT, November 2021: The Team supports the author's research priorities, encourages further discussion on the utility of conducting maturity studies across the entire GOA, and endorses the author's intent to develop an ageing error matrix and further explore natural mortality rates.

The appended CIE review discussion paper includes several sensitivity analyses: estimating male natural mortality and assuming that age at 50% maturity is 2 years younger or 2 years older than the current maturity curve in the model. In this document, we present a model run using a newly-calculated ageing error matrix to the model. Further maturity field studies have not been conducted to date.

SSC, November 2021 (suggestions): The authors discussed several research priorities, including development of an aging error matrix (SSC recommendation in 2017), exploration of natural mortality rates, updated information on maturity-at-age, and research into mechanisms behind the different growth patterns between Western-Central GOA and Eastern GOA (e.g., genetic and/or environmental). The SSC supports these areas of future work. The SSC notes that differences in growth patterns between these areas are also observed in other species and suggests that exploration into this phenomenon be done within a broader context that includes other flatfish species that may, or may not, display a similar pattern.

See response to GOA PT, November 2021 comment. Exploration of differences in growth patterns across space for flatfish species in the GOA is underway.

Responses to 2025 CIE reviewer comments

Addressing uncertainty in natural mortality *– reviewers suggested estimating natural mortality with a prior. Ideas included basing a prior on Hamel and Cope (2022), considering whether natural mortality is linked to predation, and considering time-varying natural mortality.*

The CIE discussion paper (Appendix 6A) did a sensitivity analysis estimating male M in both areas while continuing to fix female M, and shows small differences in natural mortality between sexes (0.18 yr^{-1} for males, while female natural mortality is fixed at 0.17 yr^{-1}. It is possible that there is some information in the data on M, particularly if the age of the plus group is extended in future models, given the history of light exploitation for the stock, and only in the Western-Central GOA. The Eastern GOA is essentially unexploited. However, there are some limitation in Stock Synthesis 3 for estimating natural mortality within the two-area setup. In particular, there are 4 natural mortality parameters (for the two areas and two sexes) and they are estimated completely separately by area with no ability to assume one natural mortality for females that applies to both areas, for instance. Perhaps the best first step is to conduct joint likelihood profiles for natural mortality and survey catchability, where all natural mortality parameters are set equal to one another.

Further exploration of diet data and potential environmental impacts contributing to time-varying natural mortality could be explored as well, but may be longer-term goals.

Evaluate steepness parameter assumptions and alternatives *– One reviewer commented that a steepness of 1 is appropriate given the lack of information about recruitment at very low spawning biomass values (not observed to date). Two reviewers commented that assuming a steepness of 1 is a strong assumption. Their recommendations included conducting a sensitivity analysis, or using a lower fixed value (h = 0.72 from FishLife) due to asymmetric risk concerns outlined in Hordyk et al. (2019).*

A sensitivity analysis setting steepness to 0.72 (and/or other values) can be done for the November 2025 assessment. We agree that there is little information on steepness in the data, given that we have never observed this stock at low spawning biomass values.

Dealing with impacts of uncertainty in maturity-at-age *– Reviewers agreed that the impact of uncertainty in maturity-at-age (shown in sensitivity analyses provided to them in a discussion paper - Appendix 6A) should be considered in ABC decision rules. Two reviewers suggested ensemble modeling to account for the uncertainty in maturity. Reviewers agreed that additional maturity-at-age data should be collected in the future.*

We intend to bring forward the sensitivity analyses for maturity-at-age that were presented in Appendix 6A via the Risk Table framework for the November SAFE for the purpose of considering this large source of uncertainty for GOA rex sole in ABC decision rules. Ensemble modeling has been considered for other stocks in this region, but requires decisions about model weighting in addition to substantial discussion time in reviewer forums. We suggest using a similar approach to that used for BSAI Northern rock sole in 2022, where the OFL from a sensitivity analysis was used as the reduced ABC to reduce the probability that the true, but unknown OFL exceeds the ABC. (A previous SSC recommendation for all stocks requested that authors consider the probability that the true, but unknown OFL exceeds the ABC.) We are open to alternative suggestions for accounting for uncertainty in maturity-at-age in ABC determination.

Add additional model diagnostics *– one reviewer recommended a number of additional model diagnostics that may be helpful, including runs tests, hindcast cross-validation MASE, forecast skill, likelihood profiles and production functions, and using Kell et al. (2024) to define model selection criteria.*

We agree that additional model diagnostics would be useful. The November SAFE will include as many additional diagnostics as possible within the time constraints.

Data weighting considerations*- Reviewers found the Francis (2011) data weighting to be appropriate, and suggested exploring more than one data-weighting method to determine the impact to model results, such as McAllister-Ianelli and Dirichlet-Multinomial methods. One reviewer suggested changing sigmaR to 0.636 from 0.6, following the value in Thorson et al. (2014) for flatfish. Another review suggested exploring the interaction of data weighting with values of sigmaR and natural mortality.*

We agree that exploring and discussing the impact of more than one data-weighting approach would be useful and will aim to do this for the November SAFE. We can also do a sensitivity analysis changing sigmaR to 0.636. Exploring the interaction of data weighting with values of sigmaR and natural mortality is a worthwhile, but longer term goal.

Data considerations *– All reviewers agreed that creating a GOA rex sole-specific aging error matrix would be useful. In addition, reviewers agreed that it would be useful to collect more maturity data over a broad spatial range in the Gulf of Alaska. Two reviewers suggested using model-based survey indices. Other recommendations included re-estimating weight-length relationships for each new assessment,* *adding the ADF&G small mesh survey to the assessment, and doing additional herding studies to inform survey catchability.*

We've created and included an ageing error matrix for this document. We may be able to re-estimate the weight-length relationship for the November SAFE document, however previous data explorations of the weight-length relationship (conducted in 2017) showed little change in this relationship over time. Including the ADF&G small mesh survey and using model-based indices may be feasible on a shorter-time scale for the 2029 full assessment. We agree that collecting additional data to inform maturity-at-age is a high priority for this stock, as resources allow. The fishing industry has been willing to help with this effort in the past, but it appears that we need collections to occur on research surveys with higher selectivity for smaller, younger fish. Collecting further maturity and herding data may be longer term goals given current constraints on resources.

Explore time-varying biological processes with appropriate prioritization – *Two reviewers recommended investigating time-varying growth, selectivity, and/or natural mortality noting that these explorations may allow for better fits to fishery composition data. One reviewer suggested exploring environmental relationships with natural mortality and recruitment as well as time-varying predation mortality. One reviewer suggested using a time-block for estimating time-varying growth may be a simple approach.*

The 2029 assessment may be able to explore approaches to estimating time-varying selectivity, growth, and natural mortality (likely in that priority order). We could explore whether sufficient diet data exist to analyze predation mortality. The GOACLIM multi-species and end-to-end ecosystem models may be able to inform environmental and predation influences likely to impact GOA rex sole as well, as a medium to long-term goal.

Stock structure and movement dynamics – *Reviewers generally agreed that the analysis of spatial breaks in growth patterns presented in Appendix 6A showed that the growth break for GOA rex sole is similar to split between management areas used to structure the two-area model and that using the split between the Central and Eastern GOA to define the model is both adequate and the most reasonable method. One reviewer suggested estimating time-varying recruitment allocation between the two areas. Another reviewer suggested conducting a simulation study to determine the impact of the slight mismatch between the management area break and the growth break locations. This reviewer also suggested exploring potential movement between Canada and the GOA, using Canadian data on survey biomass to inform this analysis.*

We agree that using the current methodology, using the split between the Eastern and Central GOA to define the two areas of the model is the most reasonable assumption, given the spatial resolution and structure of the data. In 2017 we conducted a model run using time-varying recruitment allocation, which showed little variation in the value of the recruitment allocation parameter over time. We could explore and hypothesize about the meaning of similar or differing trends in survey biomass between the two countries, but this may not be sufficient information to change the assumptions of the current model. A simulation study for this stock is likely a longer term goal.

Introduction

Rex sole (*Glyptocephalus zachirus*) is a right-eyed flatfish occurring from southern California to the Bering Sea and ranging from shallow water (<100m) to about 800 meters depth (Mecklenburg et al., 2002). They are most abundant at depths between 100 and 200m and are found throughout the Gulf of Alaska (GOA), with the highest biomass found in the Central GOA.

Rex sole appear to exhibit latitudinal changes in growth rates and size at sexual maturity. Abookire (2006) found marked differences in growth rates and female size at maturity between stocks in the GOA and off the coast of Oregon. Size at sexual maturity was greater for fish in the GOA than in Oregon, as was size-at-age. However, these trends offset each other such that age-at-maturity was similar between the two regions. McGilliard and Palsson (2017) found that rex sole in the Western and Central GOA tend to grow to larger maximum sizes than those in the Eastern GOA.

Rex sole are batch spawners with a protracted spawning season in the GOA (Abookire, 2006). The spawning season for rex sole spans at least 8 months, from October to May. Eggs are fertilized near the sea bed, become pelagic, and probably require a few weeks to hatch (Hosie et al. 1977). Hatched eggs produce pelagic larvae that are about 6 mm in length and are thought to spend up to 9 months in a pelagic stage in the northern GOA before settling out to the bottom as 5 cm juveniles (Abookire and Bailey 2006). Rex sole are found offshore in the GOA during the spawning season and larvae are broadly distributed over the slope and shelf. Rex sole are one of several GOA flatfish species with larvae that exhibit cross-shelf transport, moving to several nearshore nursery areas where they remain as juveniles (Bailey et al. 2008, Abookire and Bailey 2006). Several flatfish species in the Gulf of Alaska, including rex sole, Dover sole, Pacific halibut, and arrowtooth flounder have shown synchrony in recruitment patterns over time that have been linked to an environmental indicator related to sea surface height (Stachura et al. 2014).

Rex sole are benthic feeders, preying primarily on amphipods, polychaetes, and some shrimp.

Management units and stock structure

In 1993 rex sole was split out of the deep-water management category because of concerns regarding the Pacific ocean perch bycatch in the rex sole target fishery. The stock within the GOA is managed as a unit stock but with area-specific ABC and TAC apportionments to avoid the potential for localized depletion. Little is known on the stock structure of this species. However, otoliths exhibit two distinct growth patterns (pers. Comm. D. Anderl 2015) and data shown in this assessment show that length of older ages in the Eastern GOA is smaller than those for the Western and Central areas.

Fishery

Please see the most recent full stock assessment for more information about the GOA rex sole fishery: https://apps-afsc.fisheries.noaa.gov/Plan_Team/2021/GOArex.pdf.

Data

The following data were included in the assessment model:

Source	Data	Years
NMFS Groundfish Survey	Survey Biomass	1984-1999 (triennial); 2001-2023 (biennial)
	Ages Conditioned on Length	1984, 1987, 1993, 1999; 2001-2019 (biennial)
	Age Composition*	1984, 1987, 1993, 1999; 2001-2019 (biennial)
	Length Composition	1984-1999 (triennial); 2001-2023 (biennial)
U.S. Trawl Fisheries	Catch	1982-2024
	Length Composition+	1982-1984, 1990-2024
	Age Composition	1992,1995,1999,2003,2005,2007,2009,2010,2012 2014-2022

*Not included in the objective function; +Not included in the objective function in years when fishery age compositions are available

Fishery Data

This assessment used (1) fishery catches from 1982-2024 (Table 1, Figure 2), (2) the proportion of individuals caught by length group and sex for the years specified in the table above) and (3) estimates of the proportion of individuals caught by age group and sex for the years specified in the table above. Unsexed individuals were assumed to be 50% female and 50% male the fishery length- and age-data in the two runs presented in this document. See Appendix A for a bridge from the assumption of the accepted 2021 model (Model 21.0), which excluded unsexed individuals from comp data.

Both model runs in this discussion paper use an updated approach to calculating fishery age compositions from the 2021 accepted model. The updated approach standard for many AFSC assessments based on Kimura (1989), where length distributions are randomly sampled from hauls and ports, lengths are translated to ages through an age-length key for the entire fishery (which for GOA rex occurs only in the Western-Central GOA), and chosen substrata (if any) are weighted by corresponding catch weight. This updated analysis uses the afsc-assessments “sampler” repository (https://github.com/afsc-assessments/sampler). For more details, see the “Bridging Analysis,” subsection “Processing of fishery data” in Appendix 6A (the discussion paper provided for the 2025 CIE review).

Sample sizes for the length and age compositions were set to the number of fishery hauls for which length or age data were collected, respectively. As the bridging analysis run updates fishery age composition data to include unsexed fish, the yearly input sample sizes for fishery length and age data were updated from the 2021 accepted model to reflect the number of hauls from which the data originated, including these unsexed individuals.

SS3 input files including all fishery data used for each model run in this paper and in Appendix 6A can be found at: https://github.com/noaa-afsc/goa_rex.

Survey Data

This assessment used estimates of total biomass for rex sole in the Gulf of Alaska from triennial (1984-1999) and biennial (2001-2021) groundfish surveys conducted by the AFSC’s Resource Assessment and Conservation Engineering (RACE) division to provide an index of population abundance (Table 2). The preferred model separated estimates of biomass for eastern GOA from biomass estimates from the western and central regions (Table 2). Although survey depth coverage has been inconsistent for depth strata > 500 m, the fraction of the rex sole stock occurring in these depth strata is typically small, so the survey estimates of total biomass were not corrected for missing depth strata.

Estimates of the total number of individuals by length group (length compositions) from each RACE GOA groundfish survey were included in the assessment. Additionally, the assessment model fits to conditional age-at-length data. Survey age data were available for all survey years except for 2021. The age data for 1990 were excluded from the model because the underlying ages may be biased due to the age reading technique (surface age reading) used to process the otoliths.

Number of hauls for which length samples exist was used as effective sample size for length composition data. Number of otoliths aged was used as effective sample size for conditional age-at-length data. Samples collected in the Eastern GOA were entered separately from data in the Western-Central GOA.

Both Models presented in this paper make small corrections from the survey data used in the 2021 assessment, which are described in an analysis bridging from the 2021 model to an updated base case (Appendix 6A).

SS3 input files including all survey data used for each model run in this paper and in Appendix 6A can be found at: https://github.com/noaa-afsc/goa_rex.

Analytic Approach

Model Structure

The assessment was a split sex, age-structured statistical catch-at-age model implemented in Stock Synthesis version 3.3 (SS) using a maximum likelihood approach. SS3 equations can be found in Methot and Wetzel (2013) and further technical documentation is outlined in Methot (2009). Age classes included in the model run from age 0 to 20. The oldest age class in the model, age 20, serves as a plus group. Age at recruitment was set at 3 for the purpose of projections and calculation of management quantities, as few rex sole are observed before age 3.

The model has 2-areas (Eastern GOA and Western-Central GOA) with separate growth curves estimated based on survey data from each area. The model used newly available fishery age and a conditional age-at-length approach and split the survey data by region: the Eastern GOA and Western-Central GOA. Survey biomass estimates, length composition data, and conditional age-at-length data were input separately for these two regions. A non-time-varying parameter was estimated to specify the proportion of recruits that settle in the Eastern GOA. Therefore, the model assumes that the Eastern and Western-Central GOA have a similar recruitment pattern among years. All fishery data were input to the model and associated with only the Western-Central GOA. Survey selectivity parameters and growth parameters (von-Bertalanffy k, L_{max}, and L_{min}, and the CV of the youngest and oldest fish) were estimated for each of the two regions separately. The two-area configuration was implemented because fits to fishery length and age composition data were particularly poor in all one-area models that incorporated the newly available historical fishery age data (which were presented in 2017); an examination of survey and fishery length-age data showed that fish in the Eastern GOA do not grow as large as fish in the Western-Central GOA. The fishery only operates in the Western-Central GOA. In 2017 when the two-area configuration was first implemented, we hypothesized that model fits showing an expectation of more small fish and fewer large fish in the fishery than were observed could be caused by a lack of accounting for differences in growth in the Eastern GOA as compared to the Western and Central GOA (see McGilliard and Palsson 2017 for more details).

In this paper we add one model run to a bridging exercise conducted for the 2025 CIE review (Appendix 6A, "Bridging Analysis") by estimating an ageing error matrix based on double-reads for GOA rex sole and including it in the bridged model. Therefore, the run in the Appendix 6A bridging analysis called "sampler survbio edits and new data" will be called Model 25.0 and will be considered as an updated "base case" here. A run adding an ageing error matrix for GOA rex sole to Model 25.0 (the updated base case; "sampler survbio edits and new data" in Appendix 6A) will be called Model 25.1. Models 25.0 and 25.1 include the years 1982-2024, and all available data as of February 2025.

Fishery and Survey Selectivity

The fishery and survey selectivity curves were estimated using age-based double-normal functions without a descending limb (instead of a logistic function). The SS3modeling framework does not currently include the option of estimating sex-specific, age-based logistic selectivity where both male and female selectivity maintain a logistic shape (as was used in the previous assessment models prior to moving the model to SS3). The 2015 assessment (McGilliard et al. 2015) discusses the logistic and double normal selectivity curves in detail in the context of converting the model to Stock Synthesis 3. Survey selectivity was made the same for males and females after preliminary model runs showed that male and female survey selectivity were estimated to be nearly identical. Fishery selectivity was sex-specific and the fishery occurred only in the Western-Central GOA. Very little data exist to inform fishery selectivity curves for the Eastern GOA because trawling is not permitted in most of the Eastern GOA. Yearly catches in the Eastern GOA are typically 3 t or less (Table 1).

Recruitment Deviations

Recruitment deviations were estimated for an early period from 1965-1981 and a current period from 1982-2019 with a $\sigma_R = 0.6$ and were set to mean recruitment for 2023-2024 (little information exists on 0-1 year old GOA rex sole and recruitment cannot be estimated reliably for these years).

Data Weighting

Effective sample sizes for all length and age composition data were set to the number of hauls for which lengths were measured for length compositions and number of hauls for which ages were measured for age compositions (Pennington and Volstad 1994). Effective sample size for conditional age-at-length data was set at the number of individuals. Data sources were weighted relative to one another using the Francis (2011) method for all models presented.

The Eastern GOA and Western-Central GOA length composition data shared a variance adjustment in all models. Likewise, the conditional age-at-length data shared a variance adjustment across areas; the number of hauls for which length samples existed in each region provided a weighting for data from each region relative to the other region.

SS3 input files for each model run included in this paper and in Appendix 6A can be found at: https://github.com/noaa-afsc/goa_rex.

Parameters Estimated Outside the Assessment Model

Natural mortality

Male and female natural mortality were fixed and equal to 0.17, as for previous assessments. See Appendix 6A for a sensitivity analysis where the impact of estimating male natural mortality in each area on management quantities was explored.

Weight-at-Age Relationship

The weight-at-age relationship was that used in the previous assessments (e.g. McGilliard and Palsson 2017) and is based on the weight-length relationship $w_L = \alpha L^{\beta}$ and the parameters of the von-Bertalanffy growth curve. The parameters of the weight-length relationship are as follows:

	α	β
Females	1.35E-06	3.44963
Males	2.18E-06	3.30571

Maturity

Abookire (2006) modeled female rex sole size-at-maturity using a logistic model, obtaining a value for size at 50% maturity of 351.7 mm with a slope of 0.0392 mm^{-1}. About half of the maturity samples were obtained from fishery catches and half from research trawls during 2000-2001. Using the mean length-at-age relationship estimated from the 1984-1996 survey data, the age at 50%-maturity was estimated at 5.7 years and the slope was equal to -1.113. Estimates of mean size-at-age for the maturity samples were similar to those for mean size-at-age estimated from the survey data (Turnock et al., 2005).

See Appendix 6A for sensitivity analyses where the impact of smaller and larger age-at-50% maturity on management quantities was explored.

Ageing error

Age double reads for GOA rex sole were analyzed for uncertainty between readers using the TMB implementation of the R package AgeingError: https://github.com/pfmc-assessments/AgeingError. All available age data were included for the survey and the fishery. We assumed that the data were unbiased in the absence of an age validation study. We pooled the data over readers (with simply a primary and second reader), fleets, time, and age-read method and assumed a constant coefficient of variation for ageing precision. We included the ageing imprecision matrix shown in Table 4 in Model 25.1. The maximum gradient from the analysis was -0.000613.

Parameters Estimated Inside the Assessment Model

Parameters estimated within all models were the log of unfished recruitment (R_0), log-scale recruitment deviations, yearly fishing mortality, sex- and area-specific parameters of the von-Bertalanffy growth curve, the CV in length-at-age of age 2 and age 20 fish, and selectivity parameters for the fishery and survey. The selectivity parameters are described in greater detail in the most recent full operational assessment: https://apps-afsc.fisheries.noaa.gov/Plan_Team/2021/GOArex.pdf. Survey selectivity parameters were not sex-specific and two survey selectivity curves were estimated; one for the Eastern GOA and one for the Western-Central GOA. Fishery selectivity parameters for were estimated by sex and for the Western-Central GOA only. Catchability was estimated within Model 21.0.

Growth

Sex-specific growth parameters ($L_{amax=20+}$, $L_{amin=2}$, k, CV of length-at-age at age 2, CV of length-at-age at age 20+) were estimated inside the assessment model for all models, these growth parameters were estimated separately for the Eastern GOA and for the Western-Central GOA for a total of 4 sets of estimated growth parameters (female Eastern GOA, male Eastern GOA, female Western-Central GOA, male Western-Central GOA).

See Appendix 6A for an analysis of how closely the location of the break between growth patterns aligns with the Western-Central and Eastern management areas that are modeled for the assessment.

Catchability

Survey catchability was estimated within all models with a normal prior: ~N(1.2, 0.175), based on herding studies for rex sole (Somerton and Munro 2001). Survey catchability is assumed to be equal across the two areas.

Results

Model Evaluation

Comparison of models

Figure 1-Figure 6 show comparisons of population dynamics for Models 25.0 and 25.1, as well as fits to survey biomass data, time-aggregated fits to survey length composition and conditional age-at-length data, as well as time-aggregated fits to fishery length and age-composition data.

Adding an ageing-error matrix to the model leads to very similar fits to survey biomass indices between the two models (Figure 1), as well as similar trajectories in spawning biomass and fishing intensity (Figure 2). The addition of ageing uncertainty primarily impacts uncertainty in recruitment estimates prior to 2013 and the trajectory of recruitment estimates is similar, though more variable over time for Model 25.1 (with the ageing error matrix; Figure 2, third panel). Fits to time-aggregated conditional age-at-length data look similar for Models 25.0 and 25.1 (Figure 3) with slight differences in estimates of length-at-age-3 in the two areas and CV in length-at-age-3 (Table 3). Additionally, Figure 4 shows that selectivity curves are the same across models, except for a small, but discernible difference in fishery selectivity between the two models for both females and males. Fits to time-aggregated female and male fishery and survey length composition data are almost the same, with very small differences for fits to the fishery length composition data. The largest difference in fits to data between Models 25.0 and 25.1 is for fits to time-aggregated fishery age composition data (Figure 6), where fits to data are slightly worse when accounting for ageing uncertainty (Model 25.1). In Model 25.1 underestimates the proportion of age 7 fish more so than for Model 25.0 (without an ageing error matrix) and overestimates the proportion of age 15-19 fish more so than in Model 25.0. There are also some slight differences between the two models in the proportion of the population estimated to be in the plus group (Figure 6). The estimate of survey catchability is slightly different between the models as well, with a real-space value of 1.087 for Model 25.0 and 1.093 for Model 25.1 (Table 3).

Additional results are available at: https://github.com/noaa-afsc/goa_rex.

Time Series Results

Given the similarities across models in spawning biomass, recruitment, and fishing intensity in the Appendix 6A bridging analysis and between Model 25.0 and Model 25.1 (Figure 2, Appendix 6A Figure A2) and the nature of model changes as minor, but necessary updates, an updated set of time series results will be provided in November 2025.

Harvest Recommendations

Harvest projections for Tier 3a GOA rex sole will be presented in the November SAFE document. Please see the most recent accepted full assessment for GOA rex sole for a full description of methodology for harvest recommendations: https://apps-afsc.fisheries.noaa.gov/Plan_Team/2021/GOArex.pdf.

Ecosystem Considerations

Please see the most recent accepted assessment for an analysis of ecosystem considerations: https://apps-afsc.fisheries.noaa.gov/Plan_Team/2021/GOArex.pdf.

Data gaps and research priorities

Short term priorities (potentially feasible for November 2025):

- Sensitivity runs for steepness, sigmaR, age-at-50%-maturity, and alternative data weighting approaches

- A joint likelihood profile over survey catchability and natural mortality
- Alternative data weighting
- Additional model diagnostics, prioritizing those in the AFSC guidelines
- Re-estimation of the weight-length relationship

Medium-term priorities (potentially feasible for 2029 or 2033 stock assessments):

- Estimating natural mortality with a prior (but note the limitations of SS3 in the context of a two-area model discussed in "Responses to CIE Reviewer Comments"
- Explore time-varying selectivity, growth, and natural mortality (one at a time)
- Explore the interaction between data weighting, sigmaR, and M (or update to an assessment framework that estimates sigmaR)
- Include the ADF&G small mesh survey
- Explore links between predation and natural mortality
- Explore relationships between environmental variables and population dynamics

Long-term priorities (these require additional resources):

- New maturity studies
- New herding studies
- Use of model-based indices (this may be a medium-term priority if GAP has the resources)
- New work on stock structure, including simulation analysis of the impact of the slight mismatch between the spatial break in growth patterns and the model's area delineations that follow the Western-Central and Eastern management area definitions

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Tables

Table 1. Fishery catches for GOA rex sole by management area. Asterisk denotes that 2025 catch is current as of September 1, 2025

Year	Total Catch	Western Gulf	Central Gulf	Eastern Gulf
1982	959			
1983	595			
1984	365			
1985	154			
1986	93			
1987	1,151			
1988	1,192			
1989	599			
1990	1,269			
1991	4,636			
1992	3,000			
1993	3,000			
1994	3,642	49	3,508	85
1995	4,021	220	3,628	174
1996	5,945	552	5,202	191
1997	3,296	681	2,438	177
1998	2,671	440	2,195	36
1999	3,059	603	2,393	63
2000	3,585	883	2,702	Confidential
2001	2,942	435	2,507	Confidential
2002	3,017	398	2,619	Confidential
2003	3,499	772	2,726	2
2004	1,467	527	940	0
2005	2,179	576	1,603	Confidential

2006	3,295	350	2,944	0
2007	2,851	411	2,438	1
2008	2,707	185	2,522	Confidential
2009	4,753	342	4,410	1
2010	3,669	134	3,534	2
2011	2,878	131	2,746	1
2012	2,443	215	2,228	Confidential
2013	3,700	104	3,596	0
2014	3,577	126	3,450	1
2015	1,957	76	1,882	Confidential
2016	1,749	172	1,575	3
2017	1,484	48	1,434	2
2018	1,750	83	1,665	2
2019	1,612	74	1,536	2
2020	1,238	36	1,201	1
2021	301	14	285	2
2022	696	40	655	0
2023	412	23	389	1
2024	559	23	536	Confidential
2025*	463	11	452	Confidential

Table 2. GOA rex sole survey biomass for the Western-Central GOA and for the Eastern GOA. No samples were taken in the Eastern GOA in 2001.

Year	Biomass	Log Standard Error	Biomass	Log Standard Error
1990	81,912	0.08	16,313	0.15
1993	66,071	0.05	20,901	0.09
1996	53,197	0.06	19,560	0.07
1999	55,504	0.10	19,464	0.08
2001	51,258	0.06		
2003	71,238	0.06	28,659	0.10
2005	73,365	0.06	27,795	0.10
2007	88,128	0.07	15,672	0.11
2009	101,872	0.05	22,873	0.14
2011	76,453	0.06	18,681	0.08
2013	78,065	0.11	22,913	0.14
2015	64,839	0.06	22,474	0.14
2017	77,368	0.10	20,352	0.12
2019	66,171	0.08	24,243	0.11
2021	86,209	0.06	26,124	0.09
2023	74,636	0.07	17,897	0.09

Table 3. Estimated time-invariant parameters for Models 25.0 and 25.1, excluding selectivity parameters. "WC" indicates the Western-Central GOA and "E" indicates the Eastern GOA.

	Estimate		Standard Deviation	
Parameter	Model 25.0	Model 25.1	Model 25.0	Model 25.1
M (female; WC)	0.170	0.170	NA	NA
Length at age 3 (female; WC)	14.719	13.863	0.811	0.904
Length-at-age-20 (female; WC)	46.576	46.742	0.343	0.348
VonBert K (female; WC))	0.284	0.284	0.014	0.015
CV of length-at-age-3 (female; WC)	0.174	0.161	0.014	0.016
CV of length-at-age-20 (female; WC)	0.091	0.090	0.004	0.004
M (female; E)	0.170	0.170	NA	NA
Length-at-age-3 (female; E)	14.746	13.724	1.592	1.900
Length-at-age-20 (female; E)	36.807	36.902	0.618	0.622
VonBert K (female; E)	0.288	0.293	0.037	0.039
CV of length-at-age-3 (female; E)	0.173	0.158	0.030	0.035
CV of length-at-age-20 (female; E)	0.096	0.095	0.010	0.010
M (male; WC)	0.170	0.170	NA	NA
Length-at-age-3 (male; WC)	15.105	14.143	0.931	0.989
Length-at-Age-20 (male; WC)	40.869	40.992	0.269	0.269
VonBert K (male; WC)	0.323	0.324	0.018	0.018
CV in length-at-age-3 (male; WC)	0.191	0.176	0.016	0.018
CV in length-at-age-20 (male; WC)	0.074	0.073	0.004	0.004
M (male; E)	0.170	0.170	NA	NA
Length-at-age-3 (male; E)	15.516	14.684	1.759	1.962
Length-at-age20 (male; E)	34.645	34.727	0.480	0.479
VonBert K (male; E)	0.297	0.299	0.042	0.043
CV in length-at-age-3 (male; E)	0.188	0.182	0.029	0.032
CV in length-at-age-20 (male; E)	0.079	0.077	0.009	0.009
Recruitment allocation to E	-0.833	-0.828	0.049	0.050
ln(R0)	11.562	11.532	0.084	0.086
ln(q)	0.083	0.089	0.096	0.097

Table 4. Ageing imprecision estimated based on GOA rex sole double age reads, included in Model 25.1.

Age	CV
1	0.13
2	0.26
3	0.39
4	0.51
5	0.64
6	0.77
7	0.90
8	1.03
9	1.16
10	1.29
11	1.41
12	1.54
13	1.67
14	1.80
15	1.93
16	2.06
17	2.19
18	2.31
19	2.44
20	2.57

Figures

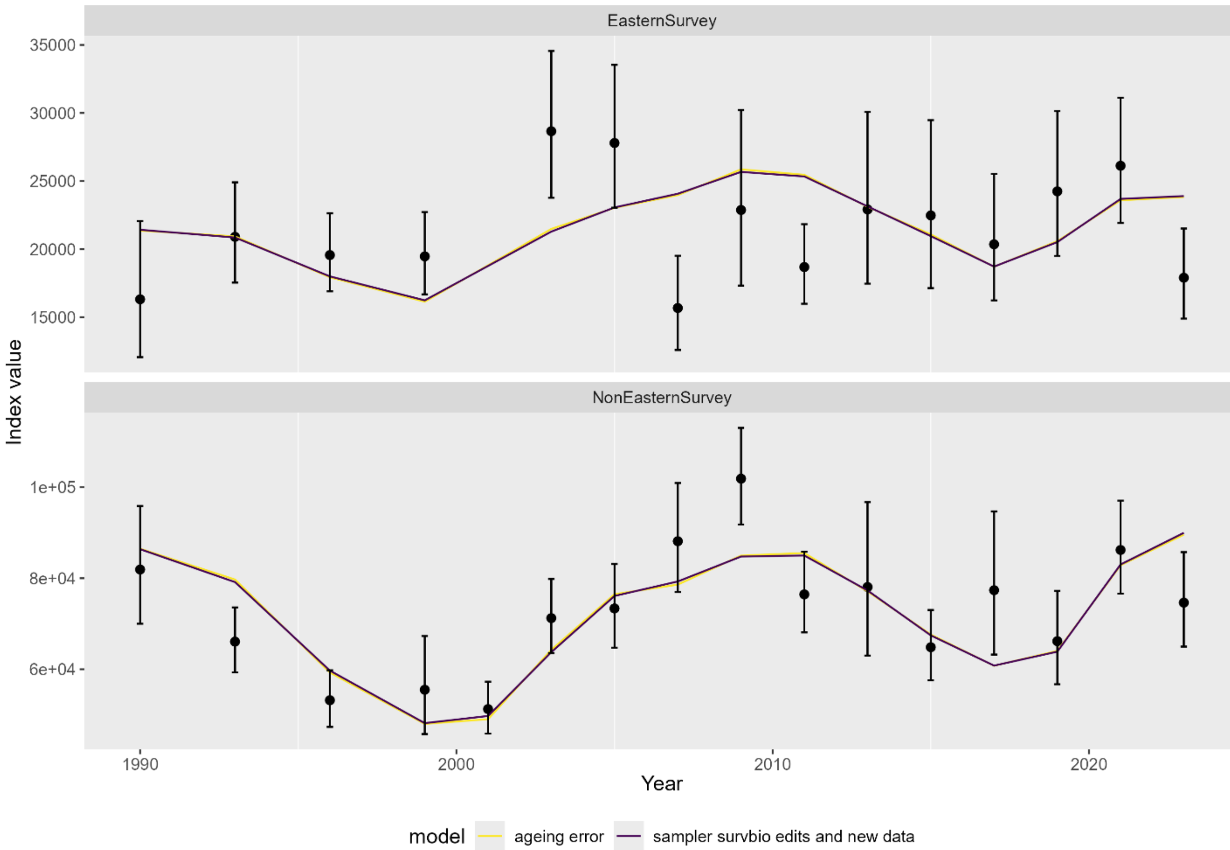

Figure 1. Observed (black dots) and predicted (lines) index of survey biomass for the Eastern GOA (top panel) and the Western-Central GOA ("NonEasternSurvey;" bottom panel) for Model 25.0 (sampler survbio and new data) and Model 25.1 (ageing error). Vertical lines show 95% lognormal uncertainty intervals.

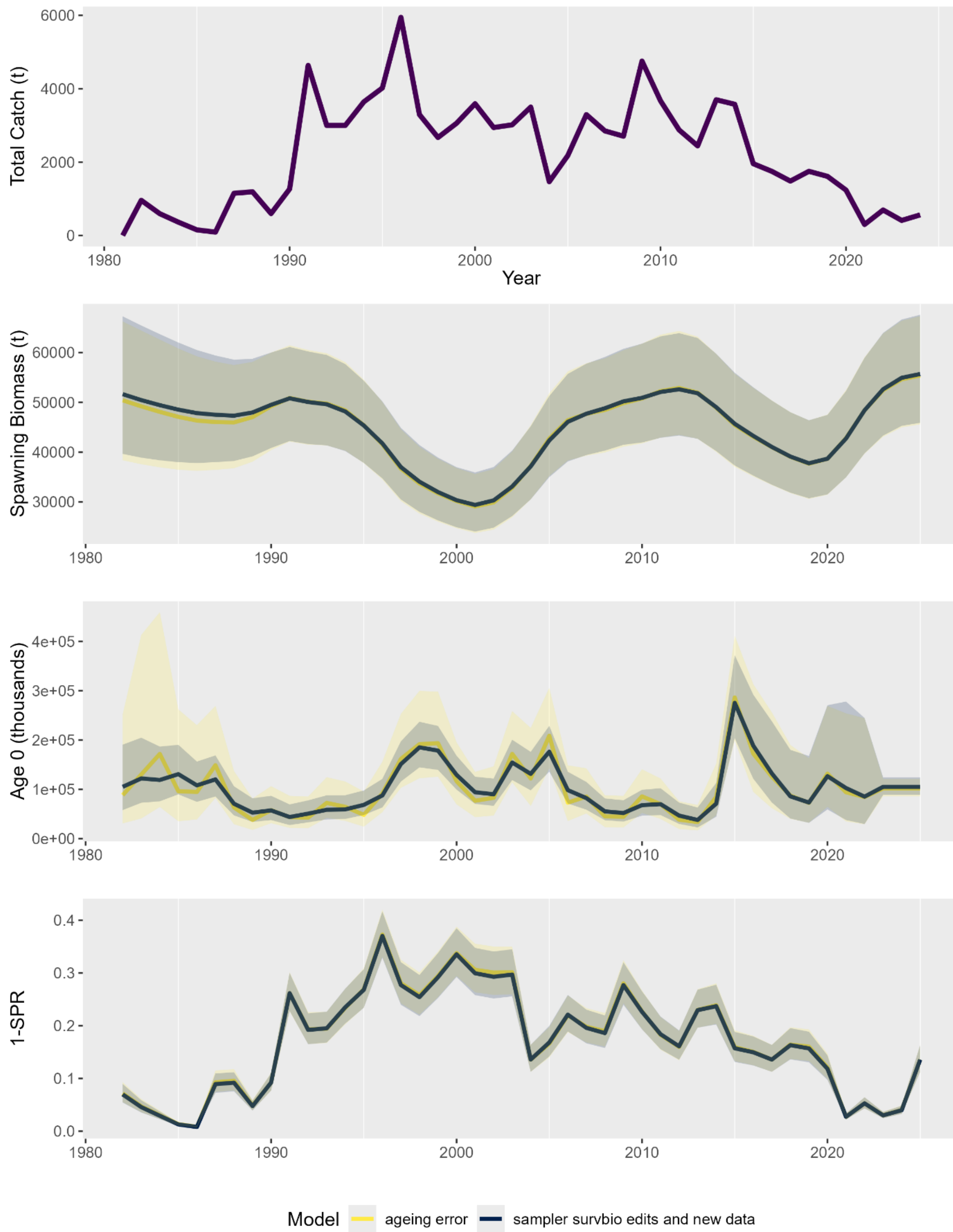

Figure 2. Observed catches and estimated spawning biomass, recruitment, and fishing intensity (1-spawning potential ratio) for Model 25.0 (sampler survbio and new data) and Model 25.1 (ageing error). Shaded areas indicate 95% asymptotic uncertainty intervals.

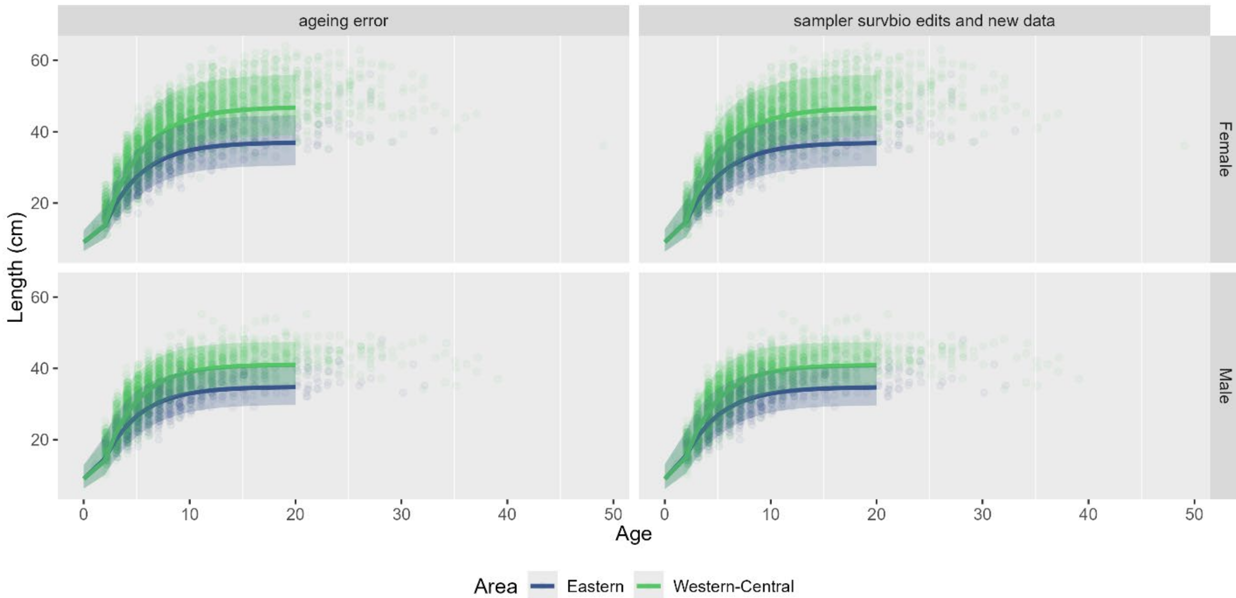

Figure 3. Raw bottom trawl survey data length-at-age by area and sex, overlaid with mean length-at-age for each model (columns) and 90% asymptotic uncertainty intervals around the means (shaded areas) for Model 25.0 (sampler survbio and new data) and Model 25.1 (ageing error). The Eastern GOA is shown in green and the Western-Central GOA is shown in blue.

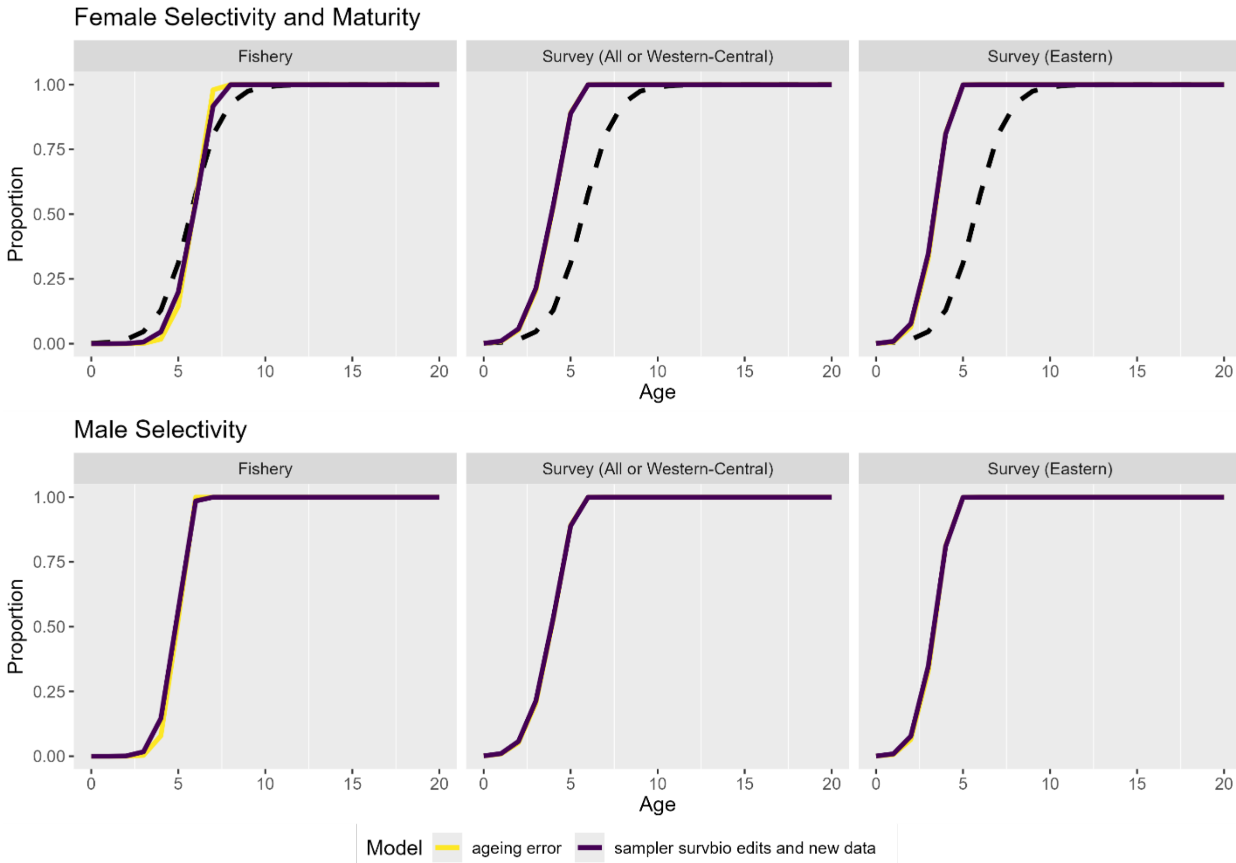

Figure 4. Fishery and survey selectivity-at-age across models for males and females for Model 25.0 (labeled "sampler survbio edits and new data) and Model 25.1 (labeled ageing error). Plots for females are overlaid on the maturity-at-age curve. A listing of selectivity parameter configurations can be found in the 2021 assessment document in Table 9 (https://apps-afsc.fisheries.noaa.gov/Plan_Team/2021/GOArex.pdf).

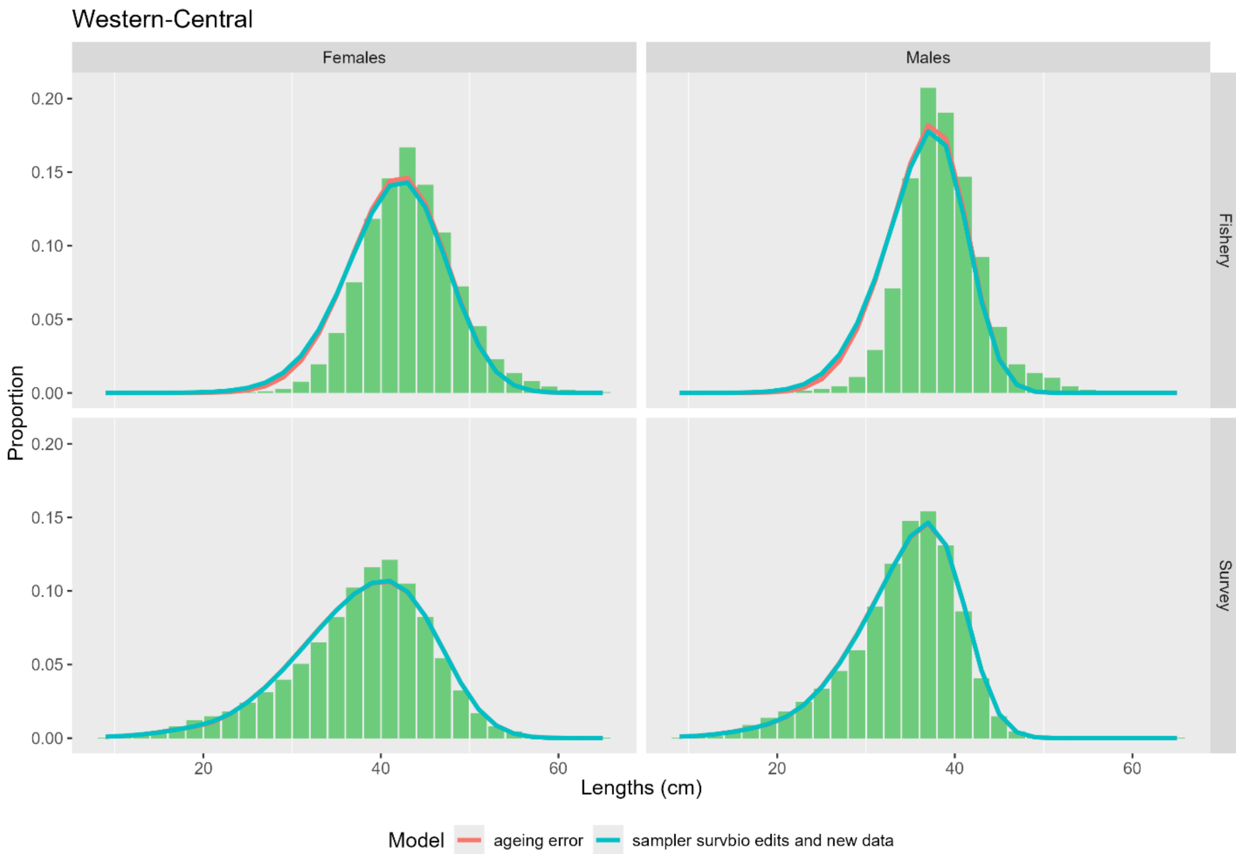

Figure 5. Fits (lines) to female and male fishery length composition with data aggregated by year (green shaded regions) for Model 25.0 (labeled sampler and survbio edits) and Model 25.1 (labeled ageing error).

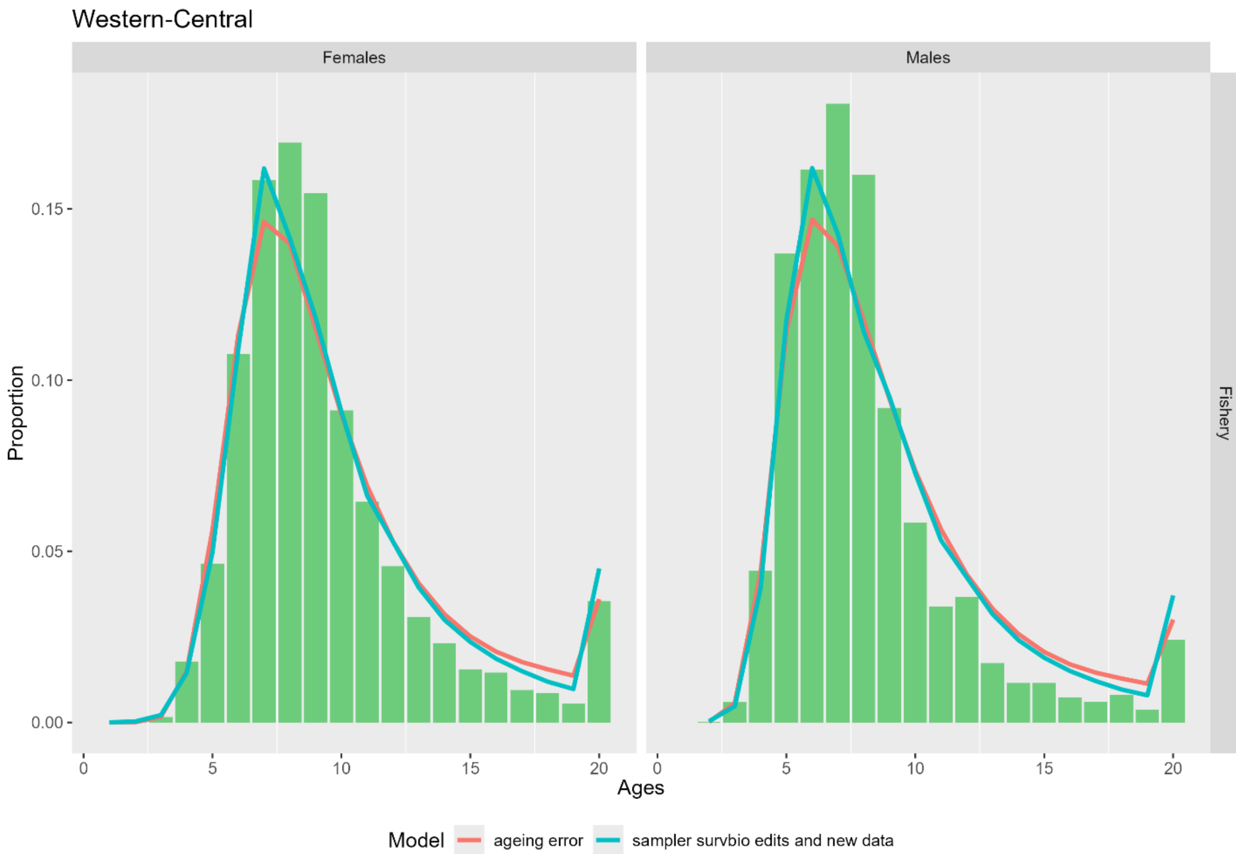

Figure 6. Fits (lines) to female and male fishery age composition with data aggregated by year (green shaded regions) for Model 25.0 (labeled sampler survbio edits and new data) and Model 25.1 (labeled ageing error). The fishery occurs only in the Western-Central GOA.

Appendix 6A: Discussion paper for 2025 CIE Review

7. Additional analyses and discussion of the Gulf of Alaska rex sole stock assessment

February 2025

Carey McGilliard, Maia Kapur, and Meaghan Bryan

This document provides additional discussion and model runs to accompany the 2021 operational stock assessment for Gulf of Alaska rex sole and was prepared for the Center for Independent Experts review in 2025. First, we present a bridging analysis (section below entitled "Bridging Analysis") that (1) re-calculates all fishery age composition data using a slightly modified approach than that used in the 2021 operational assessment, consistent with other AFSC assessment methods, (2) addresses necessary corrections to survey biomass data inputs, and (3) updates the model with new years of data that became available after the 2021 assessment cycle. We use the updated model that incorporates all changes presented in the bridging analysis as a basis to conduct sensitivity analyses for age-at-50%-maturity and estimation of male natural mortality in both areas. Lastly, we use the R package growthbreaks (https://github.com/afsc-assessments/growthbreaks), for defining spatial breaks in growth patterns to explore how well the NMFS regulatory area definitions used to define the two areas in the GOA rex sole model align with the spatial changes in growth patterns observed for the stock. Input files for the 2021 operational model and additional model runs presented in this document are available here: https://github.com/noaa-afsc/goa_rex.

Bridging Analysis

Processing of fishery data (labeled "sampler" run in figure legends)

Many older fishery age samples are port samples lacking information about the haul from which they came. Therefore, previous assessments considered approaches that would allow the use of all port samples (old port samples and any available new port samples that are missing haul information) along with the haul-level samples. Two methods utilized have been: (1) raw fishery age samples and (2) calculating proportions at age by calculating the raw length frequency of the haul or port from which the samples originated and using an age-length key to translate these distributions to numbers-at-age by haul or port, then summing over hauls and ports for a distribution of numbers-at-age (and subsequently calculating proportion-at-age). Here, we use an approach that is standard for many AFSC assessments based on Kimura (1989), where length distributions are randomly sampled from hauls and ports, lengths are translated to ages through an age-length key for the entire fishery (which for GOA rex occurs only in the Western-Central GOA), and chosen substrata (if any) are weighted by corresponding catch weight. This updated analysis uses the afsc-assessments "sampler" repository (https://github.com/afsc-assessments/sampler). A wide variety of strata can be identified to weight age distributions by the strata-specific catch biomass (optional). The "sampler" code has been accepted by the Plan Team and the North Pacific Fishery Management Council's Scientific and Statistical Committee (SSC); the method is currently used to calculate fishery age composition data for the Eastern Bering Sea (EBS) and GOA pollock stock assessments, as well as assessments for EBS Pacific cod, BSAI northern rock sole, and BSAI yellowfin sole. We did not conduct further analysis using raw fishery age samples in the model, as fishery age samples have not always been truly random (Faunce et al. 2021).

In addition, while the GOA rex sole assessment currently excludes unsexed fish from fishery length and age composition calculations, the Sampler code includes these individuals and assumes that half are female and half are male. Therefore, the run including fishery ages calculated by Sampler includes unsexed fish for both fishery length and age compositions. This run of the Sampler code assumes only one strata, while the 2021 operational model stratified by quarter and NMFS area.

There were four years for which the input sample size in the 2021 operational assessment (set to the estimated number of hauls from which fishery age data originated) where the number of hauls was not a whole number. This seems to have been a purposeful calculation done in 2017 and updated in 2021. However, I could not track down these calculations for the updated analysis. As the bridging analysis run updates fishery age composition data to include unsexed fish, the yearly input sample sizes for fishery age data were updated to reflect the number of hauls from which fishery age data originated, including these unsexed individuals. The input sample sizes are now whole numbers.

In summary, four changes were made to the fishery age composition data inputs, as follows: (1) random sampling from hauls and ports using Sampler, (2) accepting the assumption in the Sampler code to include unsexed fish that are assigned half female and half male, (3) only including one strata in these calculations, and (4) updating the yearly input sample sizes to the number of hauls (as a whole number) from which fishery age data originated to include hauls where ages for unsexed fish were collected. Though we don't show each change to fishery age data separately, collectively they make little difference to model outcomes (Figure 2-Figure 4).

Survey biomass data corrections (labeled "sampler and survbio edits" in figure legends)

There are two errors that were found in the input files for the 2021 operational assessment during the process of updating data for this discussion paper. First, the 2021 operational assessment used the coefficient of variation (CV) corresponding to survey biomass estimates as a model input for all years and areas instead of the standard error in logspace that is expected by ss3 ($\sqrt{(\ln{(1+(CV)^2}}$)). The standard errors in logspace are smaller than the CVs. Secondly, the 2021 operational model accidentally fit to survey biomass estimates for the Eastern GOA for 1984 and 1987. The Plan Team had decided to omit 1984 and 1987 survey data across all assessments due to differences in sampling methodology in those years. All new data runs omit the 1984 and 1987 Eastern GOA survey biomass indices. Adding to the model that incorporates new fishery age data inputs, we conduct a model run that uses the correct standard error in logspace for survey biomass data and exludes survey biomass estimates in the Eastern GOA for 1984 and 1987. Thus, this step of the bridging analysis clarifies the impact of the survey biomass data input errors that appeared in the 2021 operational assessment.

Figure 1 shows the survey indices with corresponding uncertainty in the index observations and fits to the survey indices for the bridging analysis. Correcting the uncertainty in observations to be the logspace standard error leads to smaller uncertainty intervals around the data points. In addition, omitting the years 1984 and 1987 from the survey index in the Eastern GOA (as was originally intended) leads to smaller estimates of catchability (q = 1.17-1.19 in bridging models excluding corrections to survey biomass data and q = 1.08 in bridging models including corrections to survey biomass data; Table 1). In turn, models that incorporate corrections to the survey biomass index data estimate higher historical spawning biomass values than for models without these corrections and slightly lower estimates of fishing intensity (1-SPR) historically (Figure 2).

Next, the following data were added to the model, in addition to the re-processed fishery age data from Sampler and incorporation of corrections to survey biomass data inputs:

- Catch biomass for 2022-2024, and updated end-of-year catch biomass for 2021
- Fishery length composition data for 2022-2024
- Gulf of Alaska Bottom Trawl survey biomass data for 2023
- Gulf of Alaska Bottom Trawl survey length composition data for 2023

For the 2025 operational assessment, we expect to have additional survey biomass data for 2025, catches for January – October 2025, newly-aged fishery age data for 2022-2024 and newly-aged conditional-age-at-length data from the GOA Bottom Trawl survey for 2021 and 2023. Figure 1 shows that the fits to historical survey biomass data are generally very similar with and without new data. However the survey biomass index in 2023 was low in both the Western-Central and Eastern GOA (Figure 1). Figure 2 shows that catches remained low from 2022-2024 and cannot explain the low values for survey biomass in 2023. Survey biomass values have declined and remained low in recent years for multiple flatfish species. A similar (but more persistent) shift to lower survey biomass has occurred for GOA Dover sole that could not be explained by fishing (there is almost no fishing for GOA Dover sole). Here, we stop to explain the approach in the 2023 GOA Dover sole assessment (https://apps-afsc.fisheries.noaa.gov/Plan_Team/2023/GOAdeepflat.pdf) for fitting to the recent shift in survey biomass in a way that accounts for uncertainty about why it occurred, as we seek feedback on how we might account for such a shift for GOA rex sole if the 2025 survey biomass is similar to that in 2023.

This paragraph on GOA Dover sole is simply meant as food for thought. This is NOT a GOA Dover sole document. The GOA Dover assessment document notes that a change in catchability and/or natural mortality could have occurred that led to persistent low survey biomass values. Because there is little fishing for Dover sole, estimating both female and male natural mortality appears to be feasible and is estimated within the model. The Dover model therefore uses a time block for recent years, where both recent catchability and natural mortality are estimated separately from historical values; this accounts for hypotheses that lower survey biomass in recent years may have been influenced by a change in catchability and/or a change in natural mortality. In the Dover model, it was not feasible to estimate historical and recent catchability along with historical and recent natural mortality. Therefore, a model was run for reference that used only data prior to the change to lower survey biomass values and estimated catchability and natural mortality without time blocks; the estimated value for historical catchability from the historical reference model was then used as a fixed value in the most recent assessment for historical catchability. In summary, the most recent GOA Dover sole model fixes historical catchability and estimates recent catchability, historical and recent natural mortality.

We do not include any model runs for GOA rex sole using the GOA Dover assessment approach for catchability and natural mortality because we still expect another survey biomass value before the 2025 assessment occurs, and it is possible that survey biomass values for 2025 will be higher than the 2023 values. In addition, the GOA rex sole model includes male and female natural mortality parameters for each of the two areas. There is not a way in ss3 to mirror natural mortality across areas that we know of, and it may not be accurate to do so, given growth differences. We welcome ideas on alternative assessment methods for accounting for a series of recent low biomass values in flatfish assessments that cannot be explained by fishing.

Growth, selectivity, catchability, mean recruitment, and recruitment allocation parameters are essentially unaffected by the addition of new data (Table 1, Figure 3-Figure 4). Likewise fits to time-aggregated fishery age and length composition data (Figure 5-Figure 6) are unaffected by the addition of available new data. Fits to fishery length composition data consistently miss larger fish that are observed and estimate a higher proportion of smaller fish than are observed (Figure 5), while time-aggregated fits to fishery age composition data estimate fewer 7-8 year old fish than were observed and more older fish than were observed (Figure 6). The fact that the fits to time-aggregated length and age composition data are skewed in opposite directions is, we think, a reflection of an imperfect line between the Western-Central GOA and the Eastern GOA and the possibility that there is some small amount of movement between the two areas. The 2017 operational stock assessment (https://apps-afsc.fisheries.noaa.gov/REFM/Docs/2017/GOArex.pdf) discusses this mismatch in detail, comparing one- and two-area models, and shows that the mismatch between fits to time-aggregated fishery age and length composition data are substantially reduced by the two-area model approach and the explicit estimation of growth in the two areas separately. However, the area delineation in the current (two-area) assessment, which follows the NMFS regulatory area definitions for the Western-Central GOA and the Eastern GOA may not be a perfect representation of the where the growth patterns diverge in space. We include further discussion of this issue as the last section of this discussion paper. Secondly, there are some small fish that occur in the Western-Central GOA (see Figure 8 from the operational assessment), especially those furthest offshore.

Table 1. Estimated time-invariant parameters for models in the bridging analysis, excluding selectivity parameters. "WC" indicates the Western-Central GOA and "E" indicates the Eastern GOA.

	Estimates				Standard Deviations			
Parameter	2021 model	sampler	sampler and survbio edits	sampler survbio edits and new data	2021 model	sampler	sampler and survbio edits	sampler survbio edits and new data
M (female; WC)	0.17	0.17	0.17	0.17	NA	NA	NA	NA
Length at age 3 (female; WC)	14.76	14.75	14.69	14.72	0.817	0.819	0.829	0.811
Length-at-age-20 (female; WC)	46.58	46.58	46.58	46.54	0.343	0.343	0.343	0.339
VonBert K (female; WC))	0.28	0.28	0.28	0.28	0.014	0.014	0.015	0.014
CV of length-at-age-3 (female; WC)	0.18	0.18	0.18	0.17	0.014	0.014	0.014	0.014
CV of length-at-age-20 (female; WC)	0.09	0.09	0.09	0.09	0.004	0.004	0.004	0.004
M (female; E)	0.17	0.17	0.17	0.17	NA	NA	NA	NA
Length-at-age-3 (female; E)	14.28	14.27	14.53	14.75	1.539	1.540	1.571	1.592
Length-at-age-20 (female; E)	36.81	36.81	36.81	36.80	0.618	0.618	0.618	0.617
VonBert K (female; E)	0.30	0.30	0.29	0.29	0.036	0.036	0.036	0.037
CV of length-at-age-3 (female; E)	0.17	0.17	0.17	0.17	0.031	0.031	0.030	0.030
CV of length-at-age-20 (female; E)	0.10	0.10	0.10	0.10	0.010	0.010	0.010	0.010
M (male; WC)	0.17	0.17	0.17	0.17	NA	NA	NA	NA
Length-at-age-3 (male; WC)	15.10	15.10	15.10	15.20	0.931	0.931	0.931	0.945
Length-at-Age-20 (male; WC)	41.02	41.05	40.95	40.87	0.274	0.275	0.268	0.269
VonBert K (male; WC)	0.32	0.32	0.32	0.32	0.018	0.018	0.018	0.018
CV in length-at-age-3 (male; WC)	0.19	0.19	0.19	0.19	0.016	0.016	0.016	0.016
CV in length-at-age-20 (male; WC)	0.07	0.07	0.07	0.07	0.004	0.004	0.004	0.004
M (male; E)	0.17	0.17	0.17	0.17	NA	NA	NA	NA
Length-at-age-3 (male; E)	15.52	15.52	15.52	15.48	1.759	1.759	1.759	1.754
Length-at-age20 (male; E)	34.64	34.64	34.69	34.65	0.493	0.493	0.495	0.480
VonBert K (male; E)	0.31	0.31	0.30	0.30	0.042	0.042	0.042	0.042
CV in length-at-age-3 (male; E)	0.19	0.19	0.19	0.19	0.031	0.031	0.030	0.029
CV in length-at-age-20 (male; E)	0.08	0.08	0.08	0.08	0.009	0.009	0.009	0.009
Recruitment allocation to E	-0.87	-0.88	-0.82	-0.83	0.060	0.060	0.050	0.049
ln(R0)	11.54	11.54	11.60	11.56	0.086	0.086	0.084	0.084
ln(q)	0.16	0.17	0.08	0.08	0.100	0.100	0.097	0.096

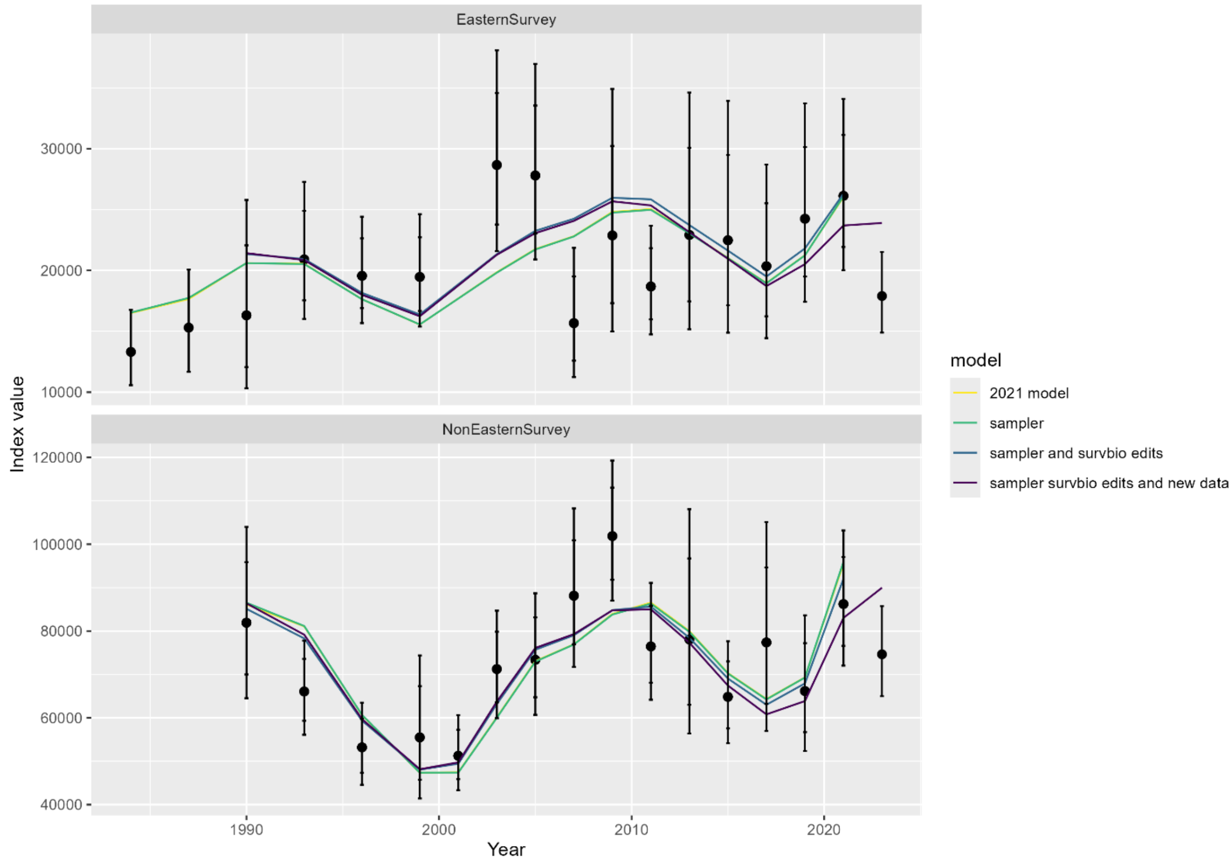

Figure 1. Observed (black dots) and predicted (lines) index of survey biomass for the Eastern GOA (top panel) and the Western-Central GOA ("NonEasternSurvey;" bottom panel) for the models in the bridging analysis. Vertical lines show 95% lognormal uncertainty intervals, with tick marks showing the smaller, correct uncertainty intervals used in models labeled "survbio edits," and the larger, incorrect uncertainty intervals used in the 2021 operational assessment. In addition, the Eastern Survey plot shows the 1984 and 1987 data points that were used in the objective function for the 2021 operational assessment, but were removed for runs with labels including "survbio edits."

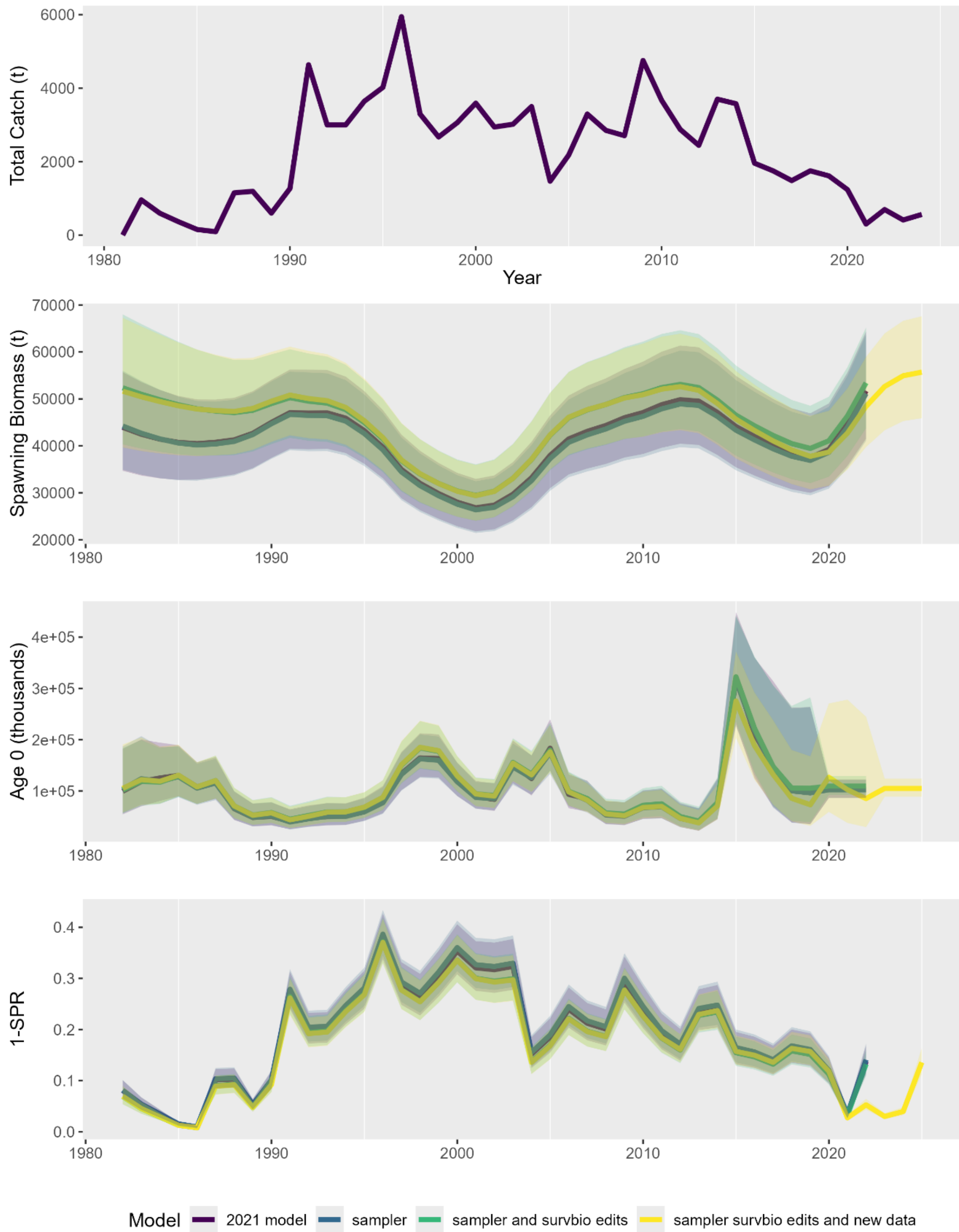

Figure 2. Observed catches and estimated spawning biomass, recruitment, and fishing intensity (1-spawning potential ratio) for the models included in the bridging analysis. Shaded areas indicate 95% asymptotic uncertainty intervals.

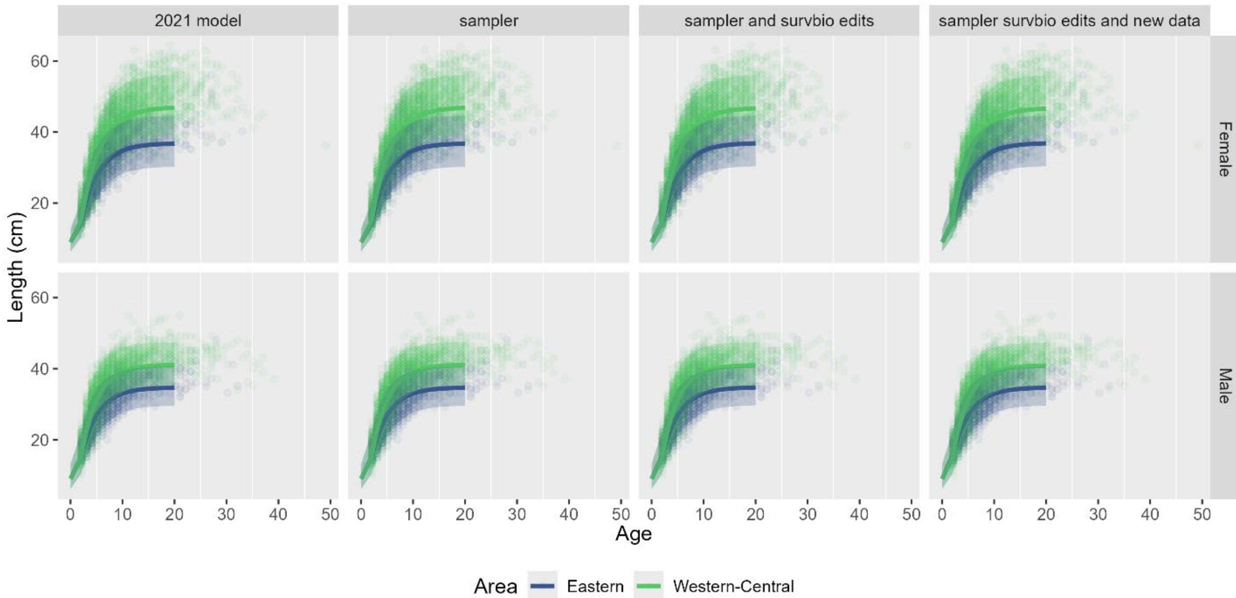

Figure 3. Raw bottom trawl survey data length-at-age by area and sex, overlaid with mean length-at-age for each model (columns) and 90% asymptotic uncertainty intervals around the means (shaded areas) for the models included in the bridging analysis. The Eastern GOA is shown in green and the Western-Central GOA is shown in blue.

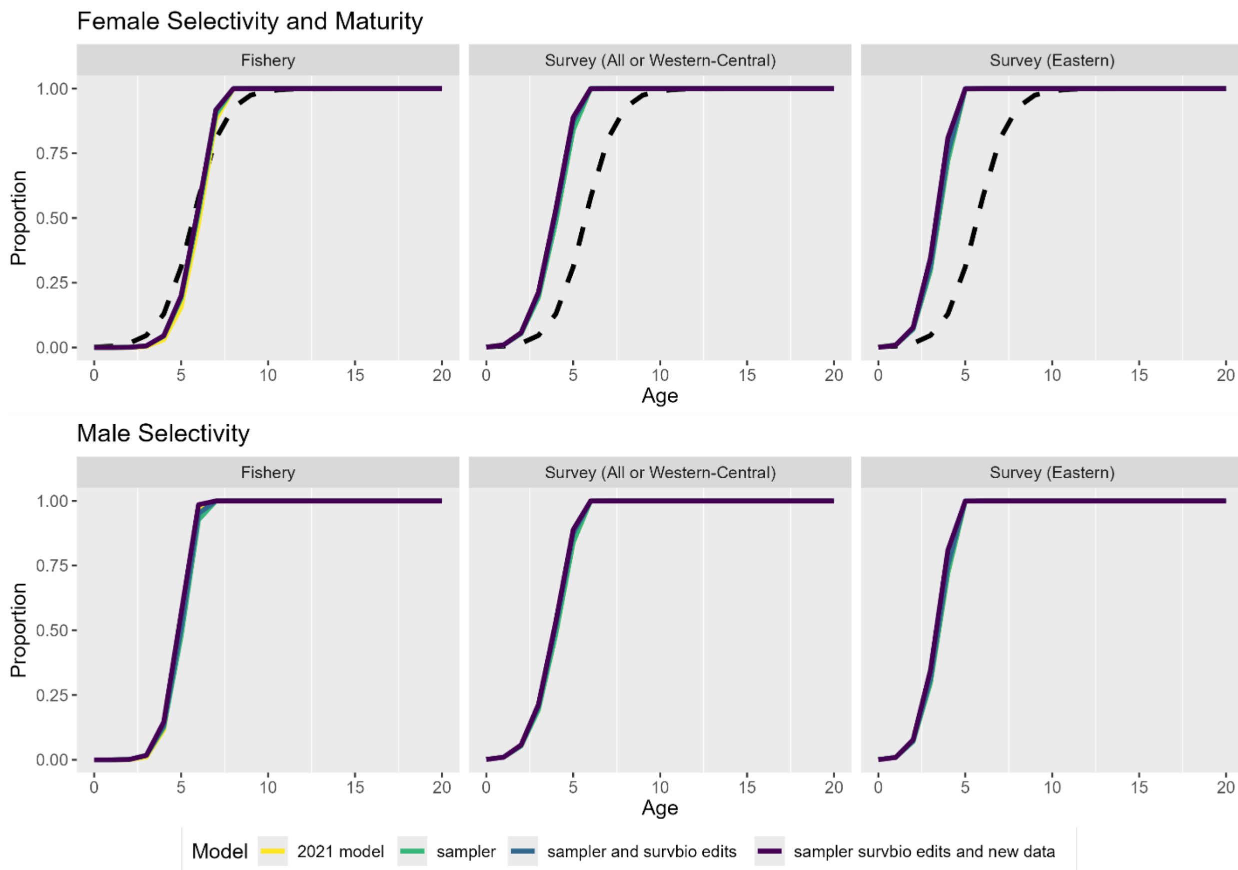

Figure 4. Fishery and survey selectivity-at-age across models for males and females for the models included in the bridging analysis. Plots for females are overlaid on the maturity-at-age curve. A listing of selectivity parameter configurations can be found in the 2021 assessment document in Table 9 (https://apps-afsc.fisheries.noaa.gov/Plan_Team/2021/GOArex.pdf).

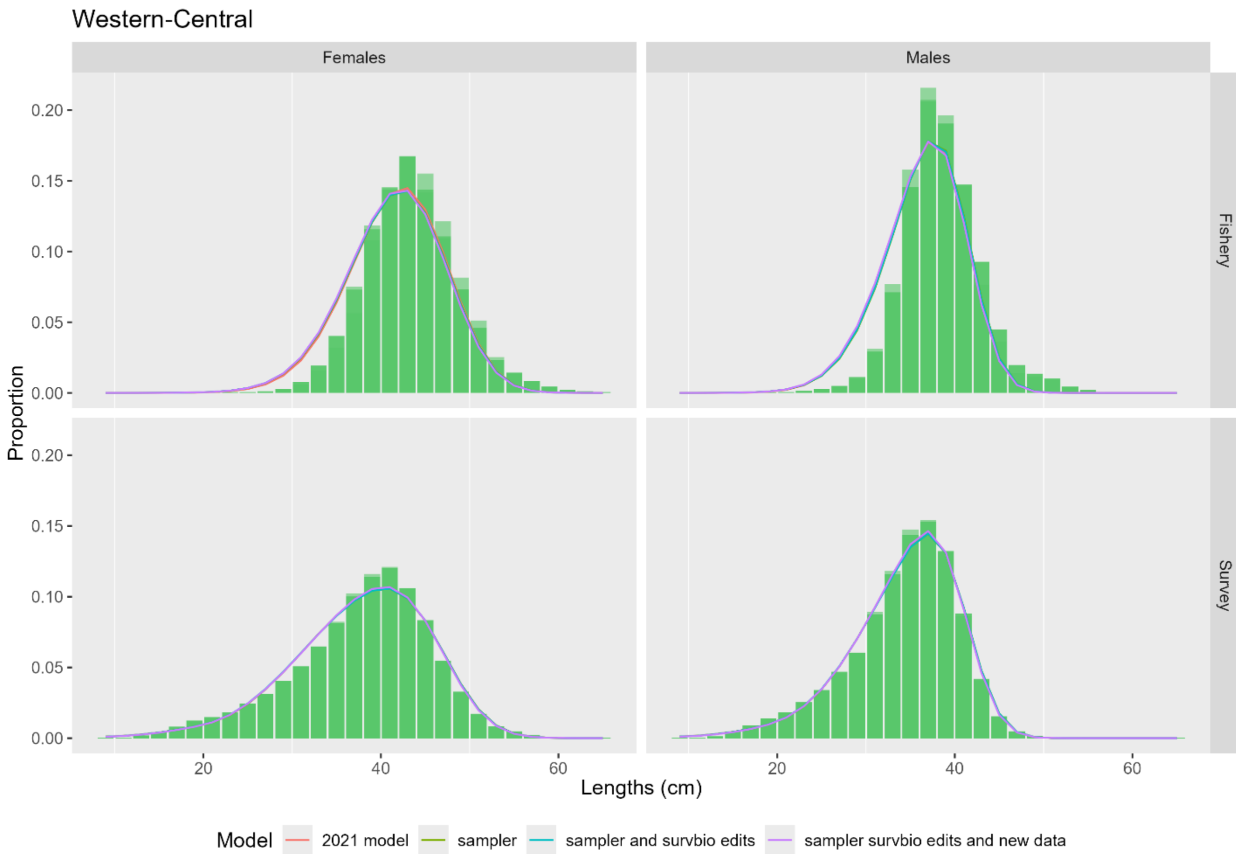

Figure 5. Fits (lines) to female and male fishery length composition with data aggregated by year (green shaded regions) for the models included in the bridging analysis.

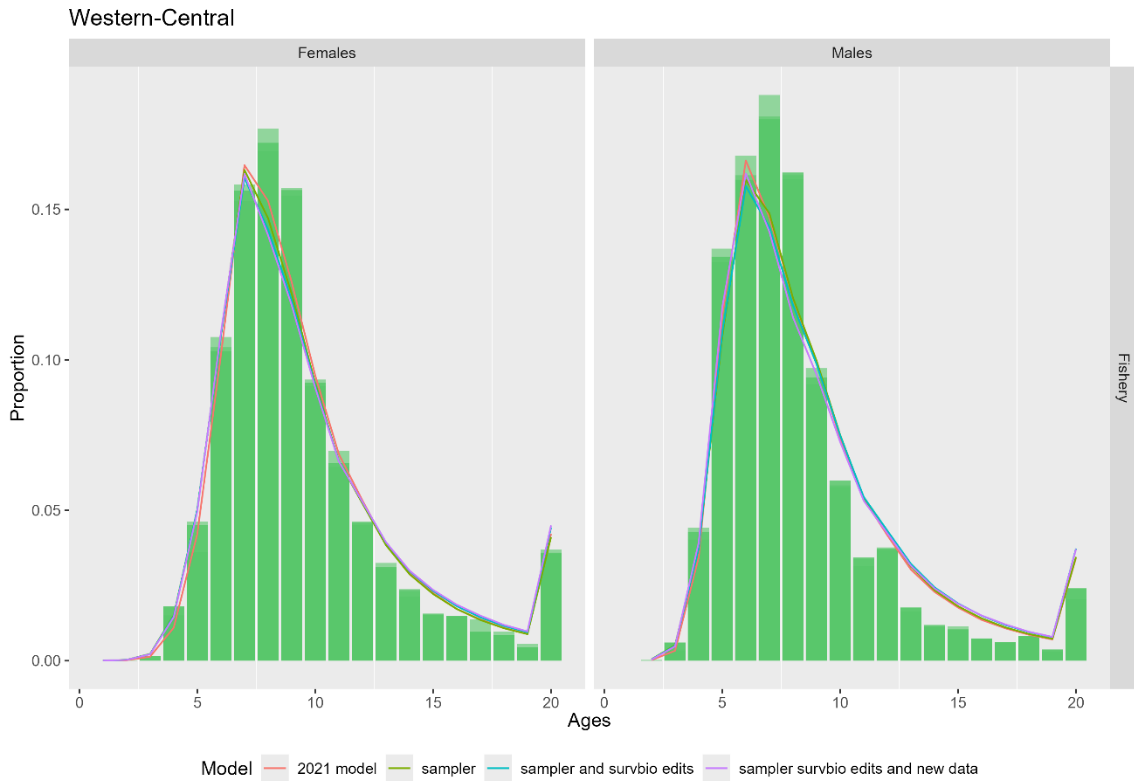

Figure 6. Fits (lines) to female and male fishery age composition with data aggregated by year (green shaded regions) for the models included in the bridging analysis. The fishery occurs only in the Western-Central GOA.

Sensitivity of the model to age-at-50%-maturity and impact of estimating male natural mortality in each area

Here, we show three sensitivity model runs. We use the model with all available new data ("sampler survbio edits new data" from the Bridging Analysis section) as a base model; we will refer to this model as the "new data" model or sometimes the "base model" in this section. Therefore, all sensitivity analysis runs include all available new data, use of sampler to process fishery age data, and all include the corrections to the survey biomass inputs.

We change the age-at-50%-maturity to be one year younger and then one year older, as well as a model run estimating male natural mortality in each area (female natural mortality is fixed). Maturity data exist only for one year, and from a very limited spatial range in the GOA. Stock synthesis 3 does not currently allow for mirroring of natural mortality estimates across areas. While natural mortality may differ by area, it is typically difficult to estimate one M value, much less 4 in an assessment model. However future analysis could do a likelihood profile, fixing female M in both areas to the same value in each iteration of the profile.

In summary we include the following runs in this section:

(1) "new data" – this model serves as the base for all of the sensitivity analyses conducted in this section. In the Bridging Analysis section, this model was labeled "sampler survbio edits new data."

(2) “early maturity” – as for “new data,” but shifting age-at-50%-maturity to occur one year earlier in the assessment (at age 4.7 instead of age 5.7).

(3) “late maturity” – as for “new data,” but shifting age-at-50%-maturity to occur one year later in the assessment (at age 6.7 instead of age 5.7).

(4) “estimate male M” – as for “new data,” but estimating male natural mortality within the model with a lognormal prior (with bias adjustment) with mean equal to 0.17 and a standard deviation of 0.2.

Table 2 shows the impact of shifted maturity and estimated male natural mortality on resulting management quantities. The estimate of survey catchability is lower for all models relative to the 2021 operational assessment (q = 1.09 after the addition of new data (with the updates to processing of fishery age data and survey biomass corrections; base model), as compared to q = 1.17 from the 2021 assessment). Estimates of male natural mortality (male M = 0.18 in each area) are slightly higher than the value of M = 0.17 from the base model, and the estimate of survey q is lower than for the base model (q = 1.01), which helps to explain why the ABC for the model estimating male M is lower than for the base model (Table 2).

Changing age-at-50%-maturity to be one year younger or older has a substantial impact on ABC, with values of 17,209 t and 12,693 t, respectively. These values can be used to inform uncertainty in the ABC for GOA rex sole. Our assessment process includes populating a qualitative “risk table” outside of the assessment model to inform any reductions from the maximum ABC value recommended from the model. In the risk table are 4 categories for assessing risk, one of which is “assessment concerns.” This is one potential route for including information about the impact of uncertainty about the maturity curve, where authors can specify on a scale of 1-3 their level of concern about assessment uncertainty; in turn, this can be used to justify lowering the ABC. Authors must decide on how much to lower the ABC and provide justification for doing so. The range of ABCs suggested by the maturity sensitivity analyses is substantial because the ages at which GOA rex sole recruit to the fishery are very similar to the ages at which maturity occurs (Figure 10). We welcome any ideas on how (or whether) to translate the range of ABCs provided by this sensitivity analysis into a reduced ABC for the stock. Impacts of the sensitivity runs on spawning biomass, recruitment and fishing intensity (1-SPR) are shown in Figure 7. Not surprisingly, a later age-at-50%-maturity leads to lower estimates of spawning biomass by approximately 5,000 t and slightly higher values for fishing intensity throughout history than for the base model (and likewise, earlier age-at-50%-maturity leads to higher estimates of spawning biomass by approximately 5,000 t and slightly lower values for fishing intensity throughout history). Estimated growth and selectivity curves are unaffected by changes to age-at-50% maturity and estimated male natural mortality (Figure 9-Figure 10), and fits to length and age composition data are likewise unaffected relative to the base model (Figure 11-Figure 12).

Table 2. Hypothetical executive summary table values for 2025 for the models in the sensitivity analysis, and also for specifications in the accepted 2024 operational harvest projections for specifying 2025 ABCs.

Quantity: (Western-Central GOA)	2025 from 2024 accepted table	2025 Accepted model, new data	2025, early maturity	2025, late maturity	2025, estimate male Ms
M (natural mortality rate)	0.17	0.17	0.17	0.17	0.17 (f), 0.18 (m)
q (catchability)	1.17	1.09	1.09	1.09	1.01
Projected total (3+) biomass (t)	104,776	95,633	95,633	95,633	102,948
Female spawning biomass (t)	50,756	45,335	48,949	41,118	51,123
$B_{100\%}$	46,850	46,488	50,038	42,394	50,874
$B_{40\%}$	18,740	18,595	20,015	16,958	20,350
$B_{35\%}$	16,398	16,271	17,513	14,838	17,806
F_{OFL}	0.28	0.27	0.33	0.22	0.27
$maxF_{ABC}$	0.23	0.22	0.26	0.18	0.22
F_{ABC}	0.23	0.22	0.26	0.18	0.22
OFL (t)	20,747	17,966	21,178	15,142	19,138
maxABC (t)	17,080	14,846	17,209	12,693	15,815
ABC (t)	17,080	14,846	17,209	12,693	15,815

Table 3. Estimated time-invariant parameters for models in the bridging analysis, excluding selectivity parameters. “WC” indicates the Western-Central GOA and “E” indicates the Eastern GOA.

	Estimates				Standard Deviations			
Parameter	new data	early maturity	late maturity	estimate male M	new data	early maturity	late maturity	estimate male M
M (female; WC)	0.17	0.17	0.17	0.17	NA	NA	NA	NA
Length at age 3 (female; WC)	14.72	14.72	14.72	14.68	0.811	0.811	0.811	0.802
Length-at-age-20 (female; WC)	46.58	46.58	46.58	46.54	0.343	0.343	0.343	0.339
VonBert K (female; WC)	0.28	0.28	0.28	0.28	0.014	0.014	0.014	0.014
CV of length-at-age-3 (female; WC)	0.17	0.17	0.17	0.17	0.014	0.014	0.014	0.014
CV of length-at-age-20 (female; WC)	0.09	0.09	0.09	0.09	0.004	0.004	0.004	0.004
M (female; E)	0.17	0.17	0.17	0.17	NA	NA	NA	NA
Length-at-age-3 (female; E)	14.75	14.75	14.75	14.75	1.592	1.592	1.592	1.596
Length-at-age-20 (female; E)	36.81	36.81	36.81	36.80	0.618	0.618	0.618	0.617
VonBert K (female; E)	0.29	0.29	0.29	0.29	0.037	0.037	0.037	0.037
CV of length-at-age-3 (female; E)	0.17	0.17	0.17	0.17	0.030	0.030	0.030	0.030
CV of length-at-age-20 (female; E)	0.10	0.10	0.10	0.10	0.010	0.010	0.010	0.010
M (male; WC)	0.17	0.17	0.17	0.18	NA	NA	NA	0.003
Length-at-age-3 (male; WC)	15.10	15.10	15.10	15.20	0.931	0.931	0.931	0.945
Length-at-Age-20 (male; WC)	40.87	40.87	40.87	40.98	0.269	0.269	0.269	0.277
VonBert K (male; WC)	0.32	0.32	0.32	0.32	0.018	0.018	0.018	0.019
CV in length-at-age-3 (male; WC)	0.19	0.19	0.19	0.19	0.016	0.016	0.016	0.016
CV in length-at-age-20 (male; WC)	0.07	0.07	0.07	0.07	0.004	0.004	0.004	0.004
M (male; E)	0.17	0.17	0.17	0.17	NA	NA	NA	0.007
Length-at-age-3 (male; E)	15.52	15.52	15.52	15.48	1.759	1.759	1.759	1.754
Length-at-age20 (male; E)	34.65	34.65	34.65	34.60	0.480	0.480	0.480	0.483
VonBert K (male; E)	0.30	0.30	0.30	0.30	0.042	0.042	0.042	0.042
CV in length-at-age-3 (male; E)	0.19	0.19	0.19	0.19	0.029	0.029	0.029	0.029
CV in length-at-age-20 (male; E)	0.08	0.08	0.08	0.08	0.009	0.009	0.009	0.009
Recruitment allocation to E	-0.83	-0.83	-0.83	-0.89	0.049	0.049	0.049	0.062
ln(R0)	11.56	11.56	11.56	11.66	0.084	0.084	0.084	0.089
ln(q)	0.08	0.08	0.08	0.01	0.096	0.096	0.096	0.099

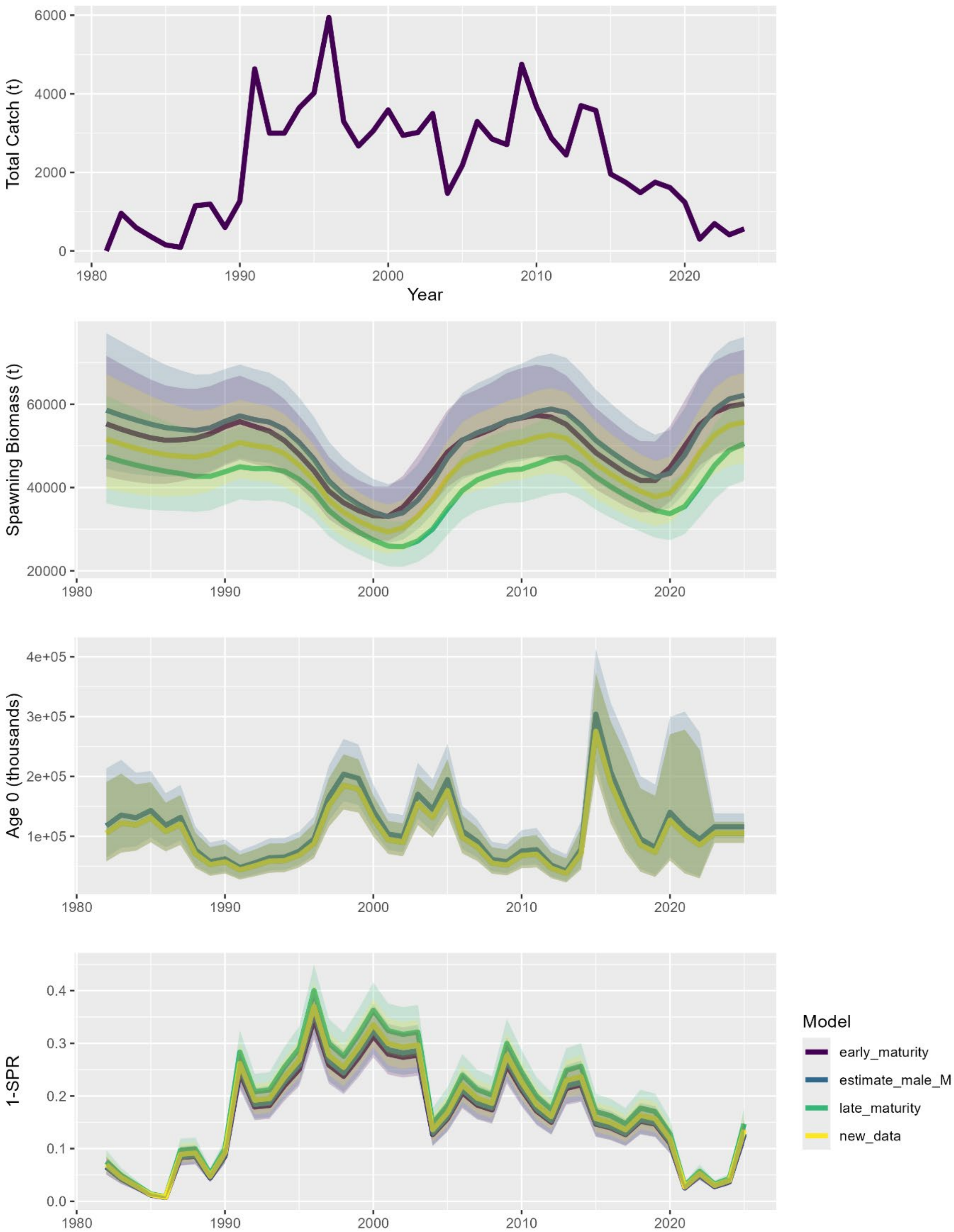

Figure 7. Observed catches and estimated spawning biomass, recruitment, and fishing intensity (1-spawning potential ratio) for each of the four alternative models with new data added. Shaded areas indicate 95% asymptotic uncertainty intervals.

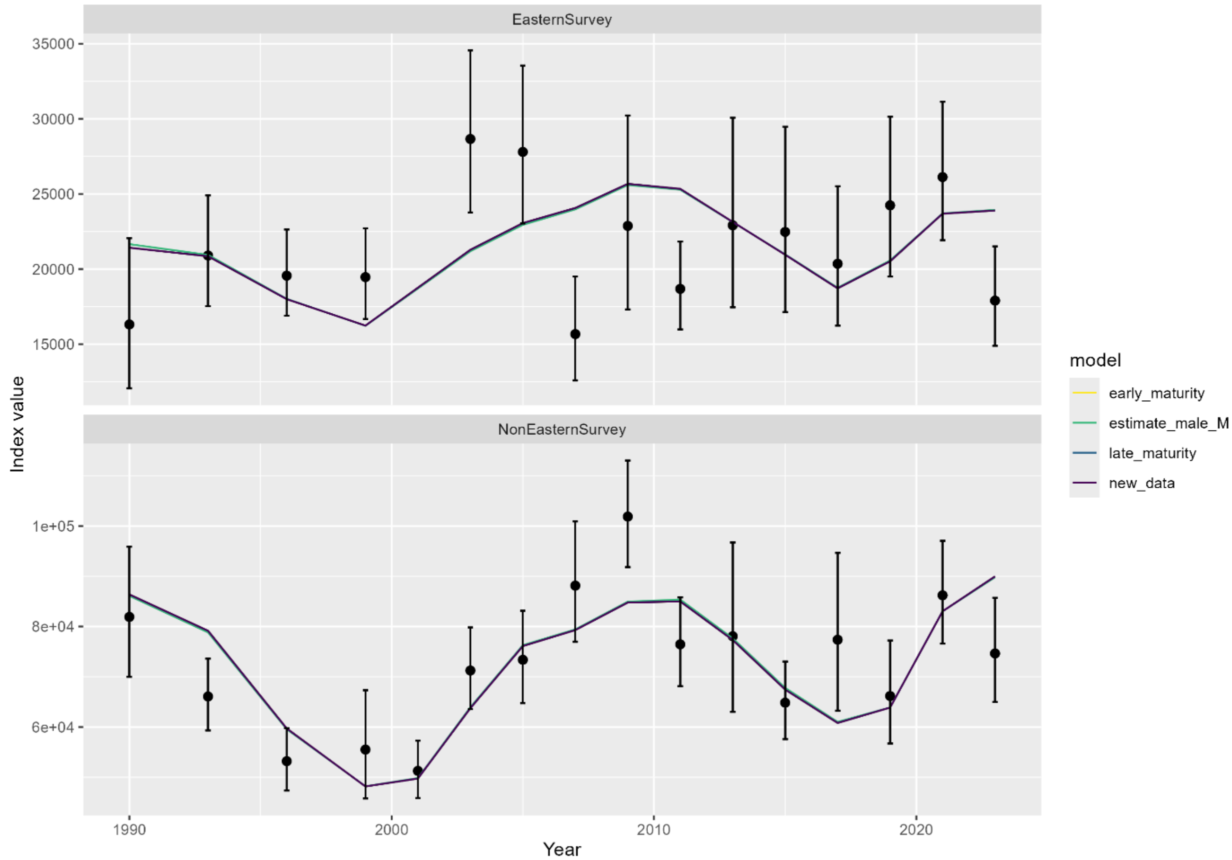

Figure 8. Observed (black dots) and predicted (lines) index of survey biomass for the Eastern GOA (top panel) and the Western-Central GOA (“NonEasternSurvey;” bottom panel) for the models in the sensitivity analysis. Vertical lines show 95% lognormal uncertainty intervals.

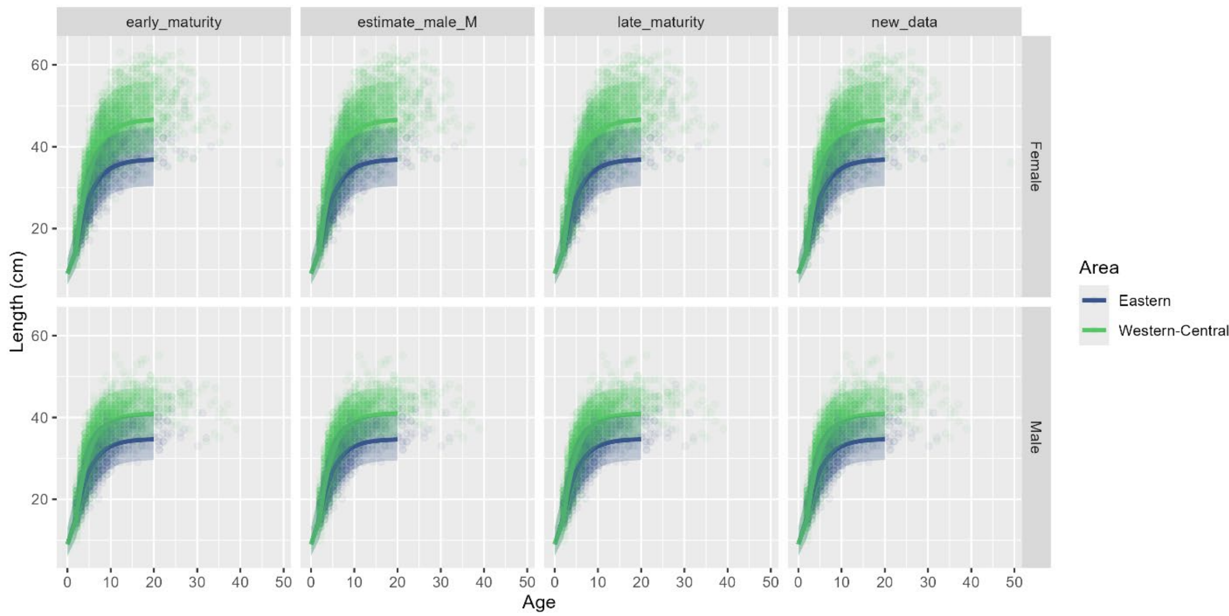

Figure 9. Raw bottom trawl survey data length-at-age by area and sex, overlaid with mean length-at-age for each model (columns) and 90% asymptotic uncertainty intervals around the means (shaded areas) for the models included in the sensitivity analysis. The Eastern GOA is shown in green and the Western-Central GOA is shown in blue.

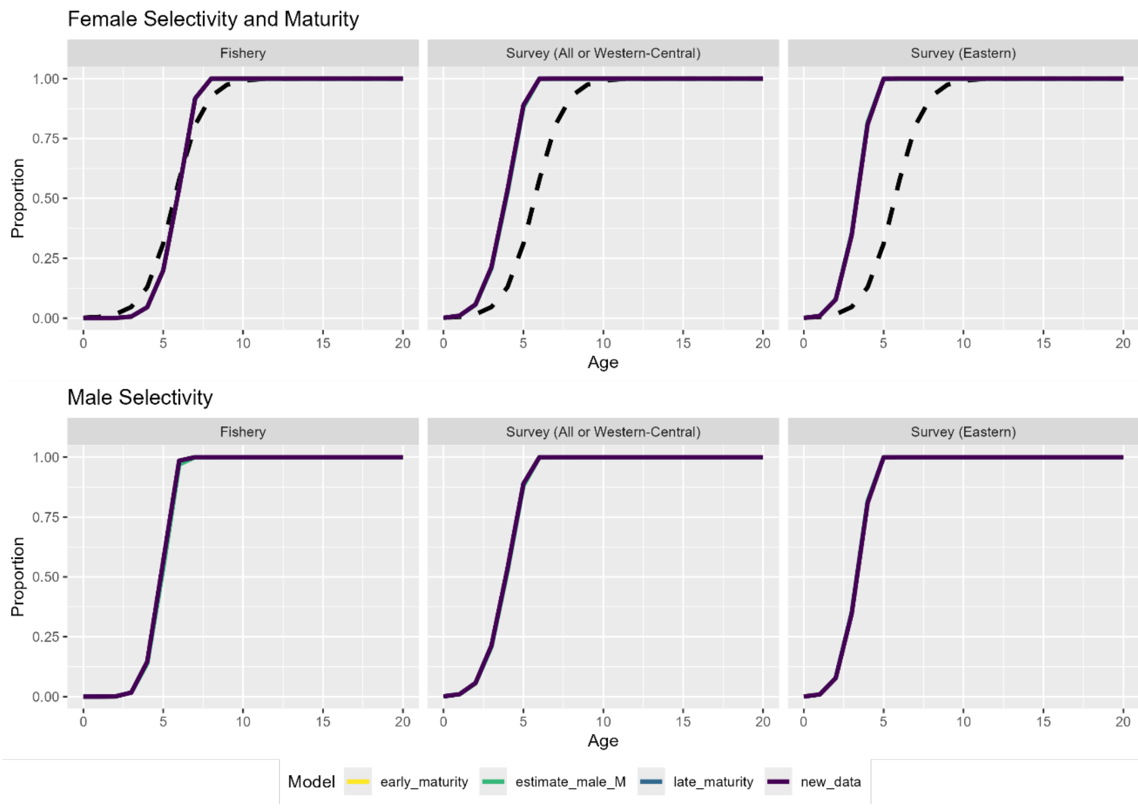

Figure 10. Fishery and survey selectivity-at-age across models included in the sensitivity analysis. A listing of selectivity parameter configurations can be found in the 2021 assessment document in Table 9 (https://apps-afsc.fisheries.noaa.gov/Plan_Team/2021/GOArex.pdf).

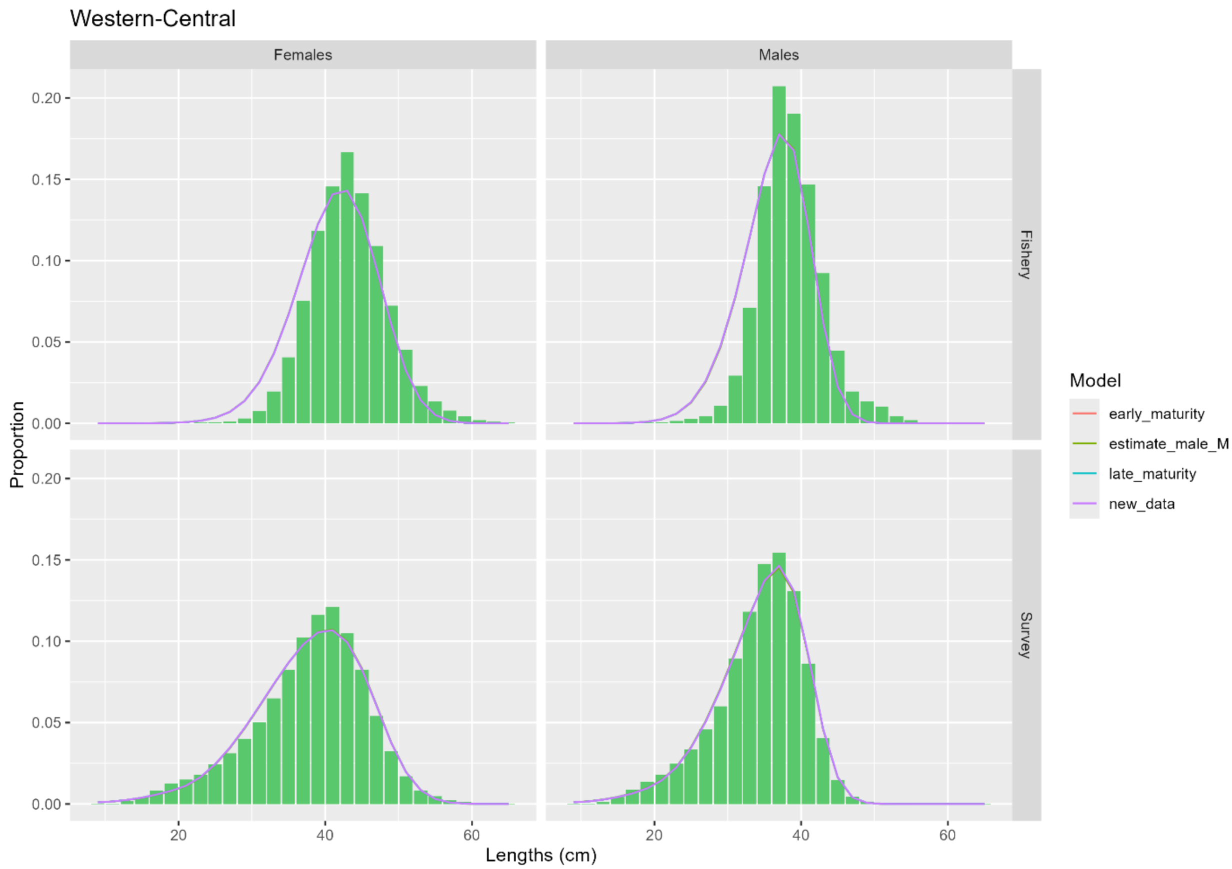

Figure 11. Fits (lines) to female and male fishery length composition with data aggregated by year (green shaded regions) for the models in the sensitivity analysis.

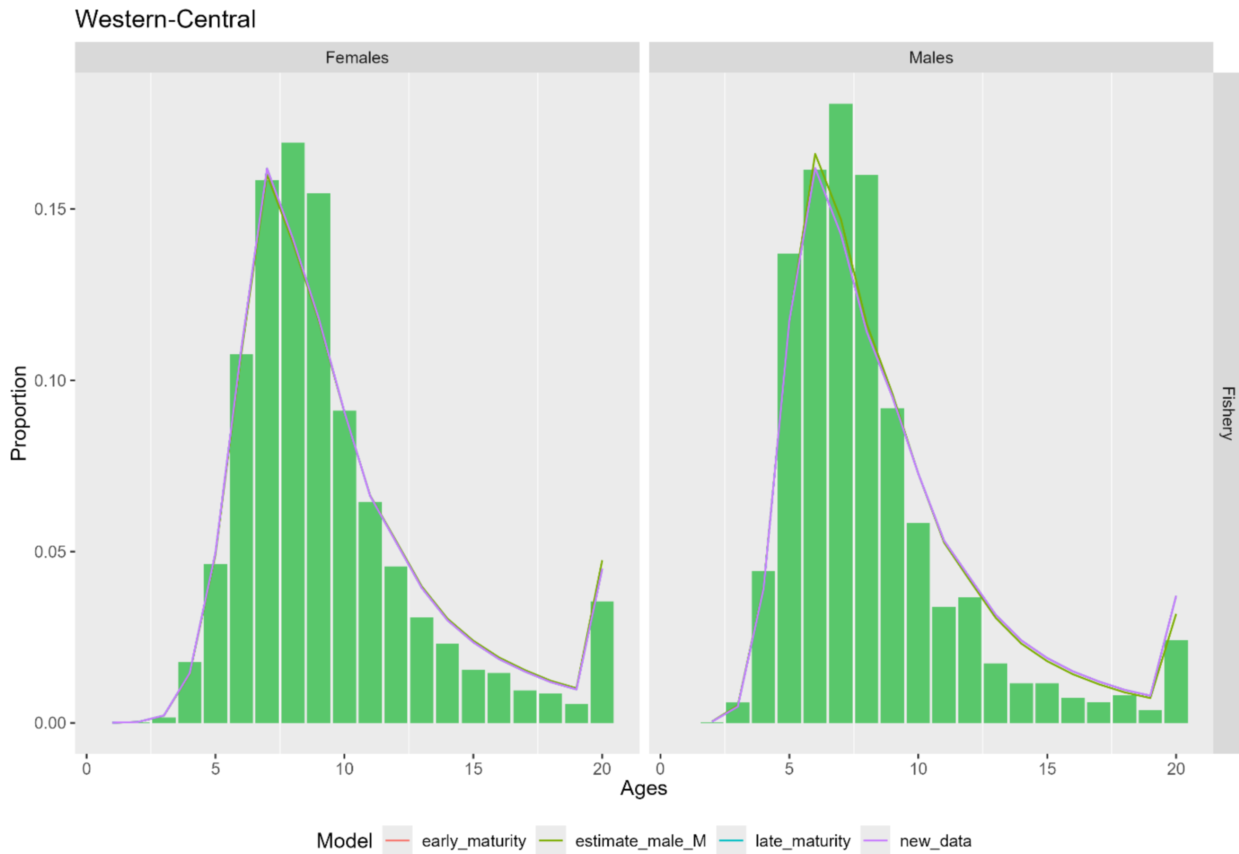

Figure 12. Fits (lines) to female and male fishery age composition with data aggregated by year (green shaded regions) for the models in the sensitivity analysis.

How well do the area delineations of “Western-Central” and “Eastern” GOA align with spatial breaks in growth patterns?

Description of GAM method

Kapur et al. (2020) introduced a GAM-based algorithm for detecting novel breakpoints in fish length-at-age. Briefly, the method fits a spatial smoother to length data for user-specified ages as a function of latitude, longitude and year, and evaluates the first derivative of the spatial smoothing function at the specified ages. The method labels a “breakpoint” at the latitude and/or longitude at which the first derivative achieves its highest value, so long as the corresponding confidence interval does not include zero. This method is intended for illustrative and inferential purposes.

Model explorations using the GAM method

We applied the method described in Kapur et al. (2020) using the R package growthbreaks (https://github.com/afsc-assessments/growthbreaks) to female length-at-age specimen data; this analysis focused on females with the assumption that female growth would have the strongest downstream effect on SSB. We first generated unique breakpoints based on the male and female data (separately) for ages 5, 10, and 15. The model detected breakpoints ranging from 150°W to 151°W and 55°N to 56°N. We re-aggregated and re-fit the von Bertalanffy growth curve at the spatial grouping that was specified by these growth breaks, and at four additional stratifications: 1) using a singular vertical break at 151°W; 2) using a singular horizontal break at 56°N, and 3) using a singular vertical break at 147°W, which corresponds to the delineation between the Western-Central and Eastern GOA NMFS regulatory areas, and is the area definition used in the assessment; 4) fitting to all data at once. All models were then compared using AIC.

This analysis revealed that among the models explored, the most parsimonious model was obtained by a singular vertical breakpoint at 151°W, which is just to the west of the definition used in the assessment (147°W; Table 4). Specifying a single vertical breakpoint at 151°W led to the best AIC value of the models included in the analysis and was a similar, but a slightly better fit to the data than the model specifying a breakpoint at 147°W which corresponds to the breakpoint in the assessment model (Table 4). The multi-area model suggested by the GAM detection method resulted in von Bertalanffy growth curves with very similar values for asymptotic length that were less distinct across latitudinal breaks than longitudinal breaks and suggested significant differences in the estimated value of the *k* parameter (Figure 13-Figure 15). Simplifying by only splitting the data into two areas east and west of 151°W led to significantly different parameter estimates for both asymptotic length and growth rate (Figure 17). These findings suggest that the length-at-age specimen data can be appropriately partitioned at vertical breakpoint at 151°W. However, the NMFS regulatory area definition is a split between the Western-Central GOA and the Eastern GOA at 147°W, and this definition is used to apportion catch limits across areas in the GOA. The AIC value for the model with a break at 147°W is slightly higher than for the model with the break at 151°W (a difference in AIC of 426), and is the second lowest AIC value of the models included (Table 4). Externally estimated von-Bertalanffy growth parameters using the 147°W split differ slightly from those calculated using the 151°W split, but are generally similar (Table 5). Given the use of the regulatory area definitions to specify area-specific catch limits, it may be difficult to use a breakpoint of 151°W.

Table 4. AIC values calculated for the growth breakpoint models, comparing model support for breaks in growth patterns between areas defined at 151°W, 147°W, 56°N, no break (Global growth curve), and multiple breakpoints (both 151°W and 56°N).

Model	AIC	dAIC
Break at 151°W	40,060	0
Break at 147°W (assessment)	40,485	426
Break at 56°N	41,183	1,123
Global growth curve	41,394	1,334
Multiple Regions (detected)	80,008	39,948

Table 5. Growth parameter estimates estimated using area definitions with no breakpoints (Global Estimates), a single breakpoint at 147°W (corresponding to the current assessment and NMFS regulatory areas), and a single breakpoint at 151°W (breakpoint with the lowest AIC value). The breakpoints analysis was conducted with lengths in mm.

	k		L_{inf}		Sigma		t0	
Area	est	sd	est	sd	est	sd	est	sd
147°W Western-Central	0.20	0.01	503.97	2.94	52.46	0.69	-0.16	0.08
151°W Western-Central	0.21	0.01	517.29	2.83	47.23	0.72	-0.09	0.08
Global Estimates	0.18	0.01	493.83	3.17	56.56	0.66	-0.42	0.09
147°W Eastern	0.20	0.01	412.98	5.42	41.84	1.12	-0.50	0.20
151°W Eastern	0.21	0.01	432.37	4.25	47.00	0.90	-0.20	0.13

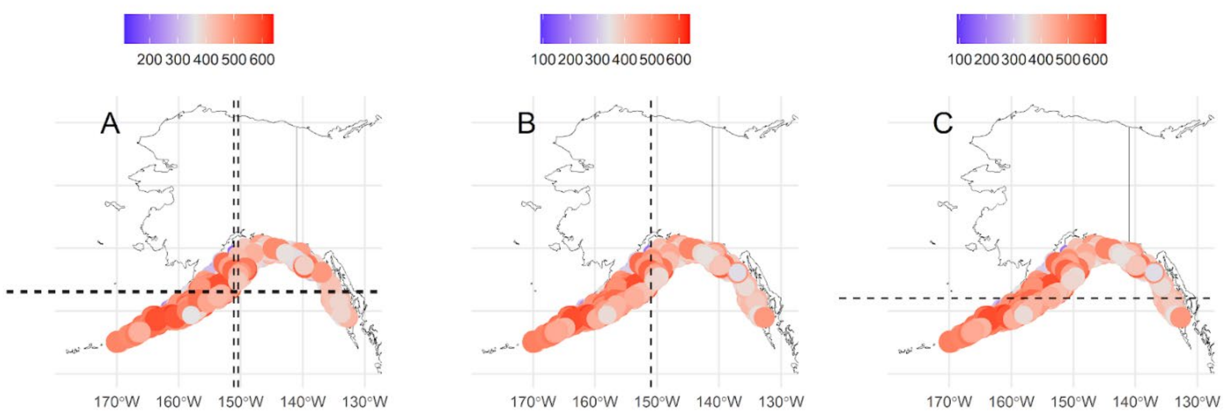

Figure 13. A) Breakpoints detected using the GAM-based clustering algorithm (Kapur et al., 2020) for female fish at ages 5, 10 and 15. B) Simplified breakpoint at 151°W as is used in the assessment model. C) Simplified breakpoint at 56°N explored for comparison. Colored points are observed lengths (in mm).

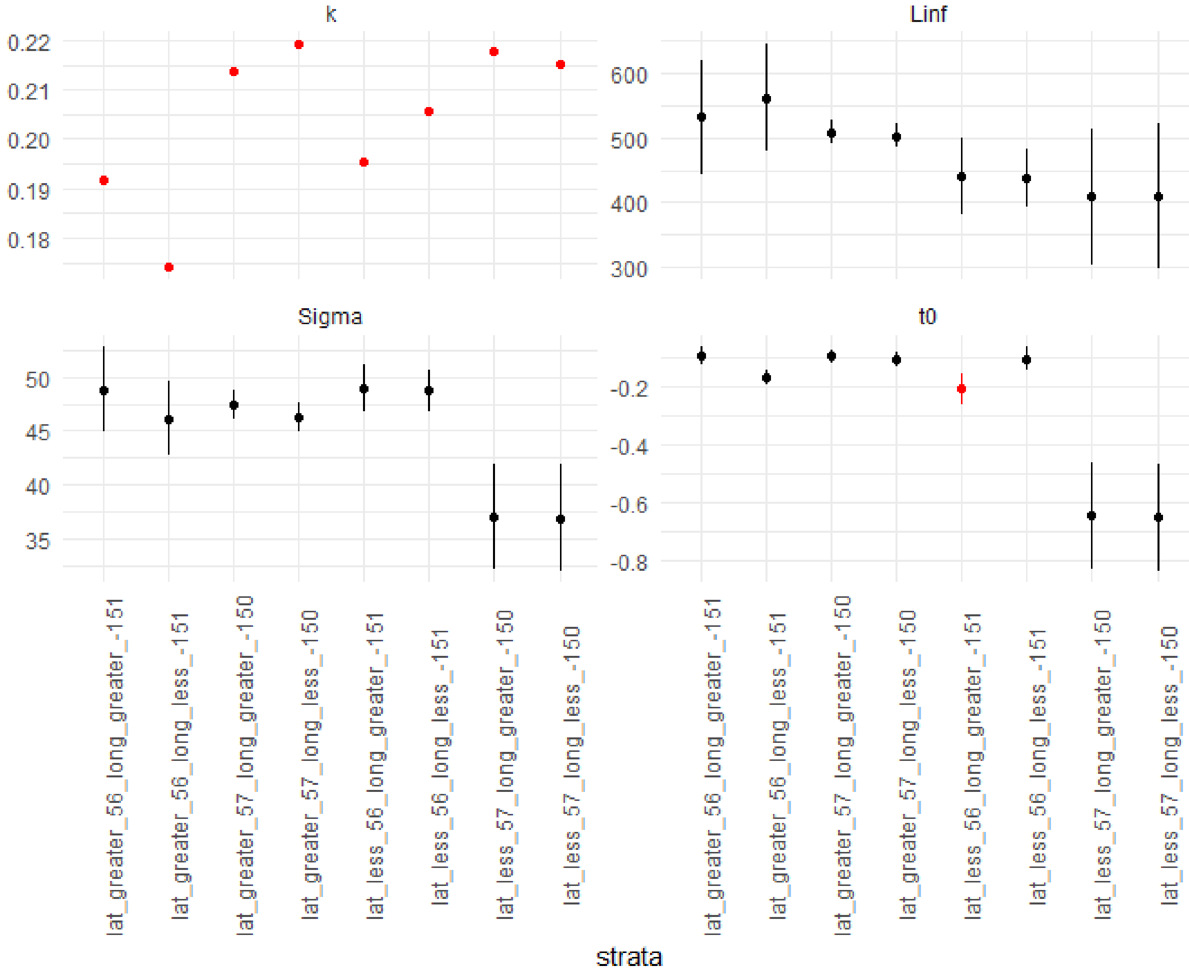

Figure 14. Von Bertalanffy parameter estimates and 95% uncertainty intervals using all detected breaks. Red points and error bars represent spatial strata for which parameter estimates were significantly different from at least one other area.

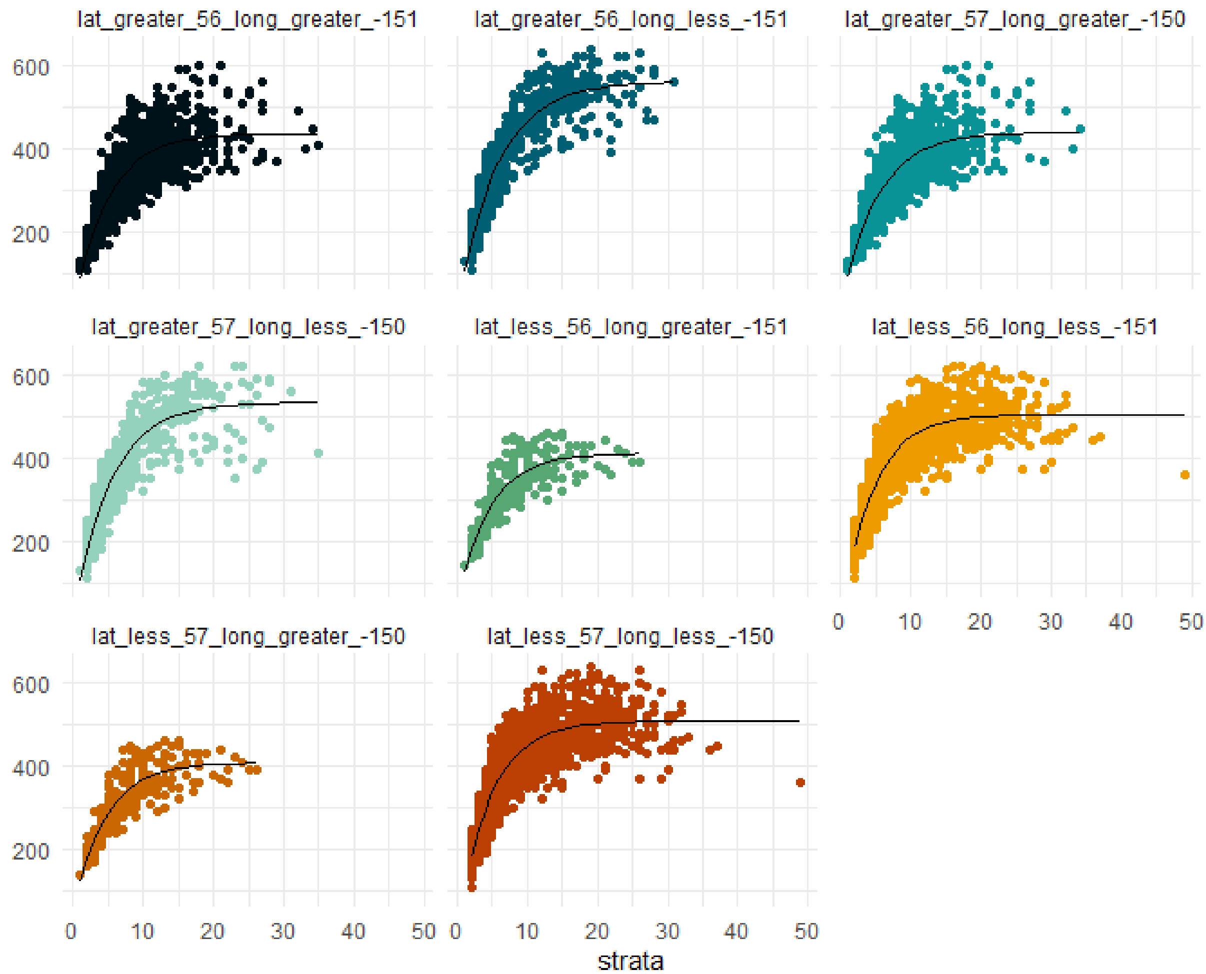

Figure 15. Estimated von Bertalanffy growth curves (solid lines) to female length-at-age data partitioned into spatial areas defined by detected breaks.

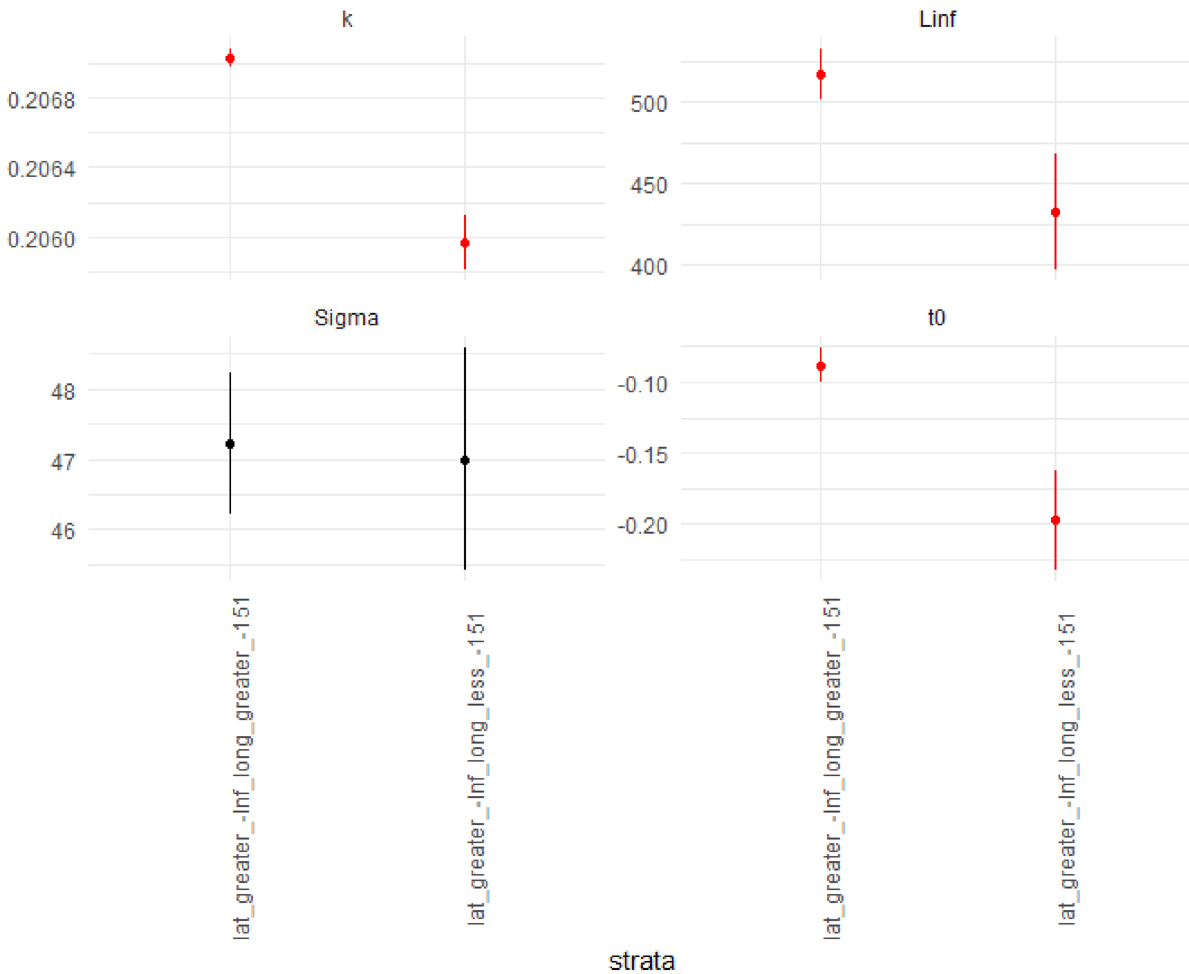

Figure 16. Von Bertalanffy parameter estimates and 95% uncertainty intervals for two-area hypothesis (as used in the assessment model). Red points and error bars represent spatial strata for which parameter estimates were significantly different from at least one other area.

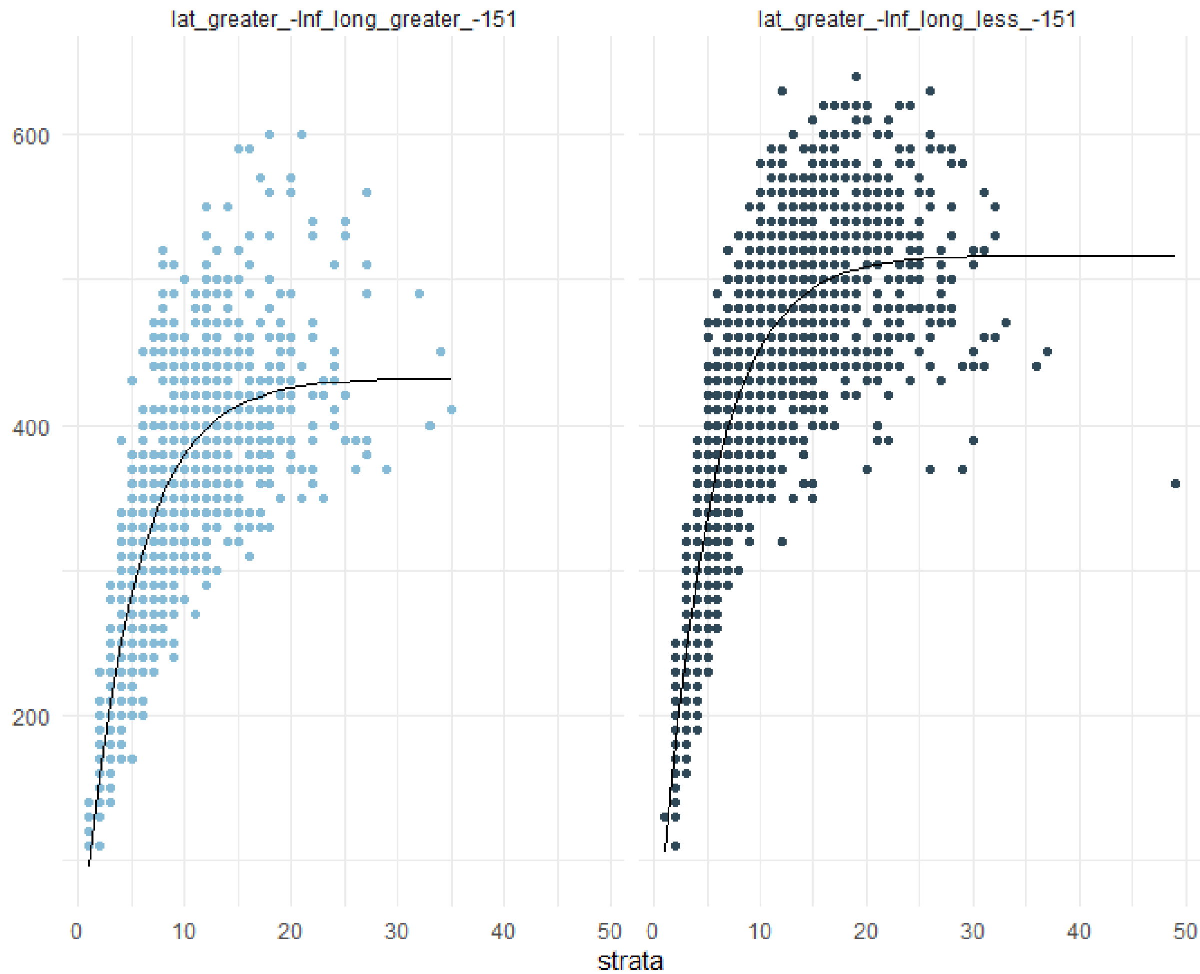

Figure 17. Estimated von Bertalanffy growth curves (solid lines) to female age-at-length data partitioned into two spatial areas (as used in the assessment model) east (left) and west (right) of 151°W.

Next steps

The authors aim to analyze double-read ages to calculate an ageing error matrix for this stock to analyze the impact of including ageing error on estimates of growth and on the model in general.

While the conditional age-at-length approach allows for estimation of growth within the stock assessment and allows uncertainty in growth to propagate through the assessment, the two-area model with internal growth estimation is a difficult setup for running MCMCs or exploring Bayesian assessment methods for this stock. However, the ADnuts package (https://github.com/Cole-Monnahan-NOAA/adnuts; Monnahan et al., 2019) may make this possible.

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